NOV 10 1925

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NOTES ON THE OXIDATION PRODUCTS DERIVED FROM CHALCOPYRITE.

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CONTENTS.

INTRODUCTION 613
Definition of Terms 615
CHEMICAL CONSIDERATIONS 615
DESCRIPTION OF THE OXIDATION PRODUCTS 618
Oxidation Products Derived from Chalcopyrite and from Chalcopyrite-Pyrite Mixtures 618
In Inert Gangues 618
Coarse Cellular Type 618
Fine Cellular Type 620
Glassy, Compact Type 622
In Environments Containing Neutralizer 624
Rapid Neutralizer 625
Moderately Slow Neutralizer 628
Very Slow Neutralizer 631
Confusion of Zonal Patterns 632
Exotic Limonites 633
Cellular Limonite Resembling that Derived from Chalcopyrite, but of Pyrite Origin 634
LIMONITE COLOR 635
SPECIFIC APPLICATIONS OF THE CRITERIA PRESENTED 635
SUMMARY 637

INTRODUCTION.

IN the study of leached croppings as guides to copper ore, prosecuted under the direction of Augustus Locke, the purpose has been to find significant differences between the oxidation products of

specific sulphides, or specific mixtures of sulphides. Such differences between chalcocite and pyrite were discussed in a paper by H. W. Morse and Augustus Locke.[1] The present paper sets forth certain oxidation products that have been found to characterize chalcopyrite and especially to distinguish it from pyrite.

Specimens were collected showing the oxidation of pure chalcopyrite and of various mixtures of chalcopyrite and pyrite in inert, or quartz gangues; in environments of rapid neutralizer, such as limestone; in environments of moderately slow neutralizer, such as feldspar; and in environments of very slow neutralizer, such as sericite. Specimens were collected which showed also the oxidation of pure pyrite, and of certain gangue minerals, such as siderite, whose oxidation products resemble those of chalcopyrite. No specimens were used whose origin could not be traced in the field by immediate gradation into the parent mineral.

The specimens came from the Bagdad, Bisbee, Morenci, and Silverbell districts, the Zonia and Reliance prospects, and the Yellowhorse Mountains, in Arizona; from Hanover, New Mexico; from the La Libertad and the Los Aliados prospects in Sonora; from the Mizpah property in Nevada; from the Cactus mine and the Big Indian property in Utah; from the Engels and the Walker mines in California; and from the Rocher de Boule mine in British Columbia. Field comparisons were made with the oxidation products found in various other parts of Mexico and the Southwest. In each district named, at least one, and often several, of the oxidation products described, were found well developed.

Acknowledgments are due Augustus Locke and H. W. Morse for assistance in planning the paper and for criticism of it; to F. L. Ransome and H. E. Merwin for criticism and suggestions after it was written; to the geological departments at Stanford University and the University of California, in whose laboratories some of the investigations were conducted; to the owners and operators of the various mining properties visited; and to

[1] H. W. Morse and Augustus Locke, "Recent Progress With Leached Ore Capping," ECONOMIC GEOLOGY, Vol. XIX., No. 3, April–May, 1924.

NOV 10 1925

the United States Geological Survey for photographing specimens.

The paper is intended for use of the scout in the field.

Definition of Terms.—In this paper the term "limonite" will be used as a field name for fine-grained, yellowish or brownish deposits from decomposing iron-bearing minerals. More definite characterization must follow laboratory study of individual specimens. Presumably the limonite will usually be ferric oxide monohydrate (geothite), but it may give place to hematite (turgite), lepidocrocite, or certain basic sulphates.[2]

"Indigenous limonite" is limonite deposited within the space formerly occupied by the sulphide or other mineral that has been oxidized.

"Transported limonite" is limonite from iron solutions that have moved a short distance beyond the limits of the sulphide—usually not more than a few centimeters.

"Exotic limonite" is limonite from iron solutions that have moved a greater distance from the limits of the parent mineral—often hundreds of feet to a place outside the mineralized body.

CHEMICAL CONSIDERATIONS.

An outstanding consideration in the oxidation of sulphides is the behavior of the liberated iron; *i.e.*, whether it is precipitated as *indigenous limonite;* whether, before precipitation, it is carried a short distance beyond the limits of the parent sulphide, and comes down as *transported limonite;* or whether it is lost altogether out of the mineralized body, and is precipitated as *exotic limonite.*

To be precipitated, the liberated iron must undergo certain changes. For convenience, these may be expressed as the steps:

(*a*) Oxidation of ferrous to ferric iron;
(*b*) Hydrolysis of ferric iron to limonite;

(*a*) Oxidation of ferrous to ferric iron is retarded by free sulphuric acid. It is rapidly accelerated with near approach of

[2] E. Posnjak and H. E. Merwin, The Hydrated Ferric Oxides, Amer. Journ. Sci., *47*, 311, 1919; also The System Fe_2O_3–SO_3–H_2O, J. Am. Chem. Soc., *44*, 1965, 1922.

the solution to neutrality. Thus, with other conditions equal, pyrite, which on thorough oxidation generates free sulphuric acid, would be more likely to export its iron than chalcopyrite, which, with its smaller proportion of sulphur, is far less likely to have free sulphuric acid left over.

To a degree not yet determined but known to be important, oxidation of ferrous to ferric iron is accelerated by copper. Thus, on this basis, with other conditions equal, chalcopyrite would be less likely to export its iron than would pyrrhotite, which has about the same proportion of sulphur to bases; and much less likely to export it than would pyrite, which has a greater proportion of sulphur to bases. A double reason therefore exists why chalcopyrite is less likely than pyrite to export its iron.

(*b*) Hydrolysis of ferric iron to limonite is likewise retarded by free sulphuric acid and accelerated by copper.[3] But with certain ratios of Fe_2O_3 to SO_3, mere dilution may make hydrolysis possible. Thus, with a proportion of 1 Fe_2O_3: 4 SO_3 (the proportion produced by the oxidation of pyrite), hydrolysis takes place when the solution is diluted to a concentration of 98.8 per cent. This means that a standard difference of behavior in the oxidation of pyrite and chalcopyrite is to be expected only under standard conditions of concentration.

There is a "lag," of undetermined magnitude, in the precipitation and in the achievement of equilibrium by the iron precipitates. Therefore, while the proper conditions of concentration for the precipitation of limonite might be reached, they might be maintained so short a time (for example the time when a given body of solution remained in one place, as between rains), that precipitation would not occur at the expected place.

For these reasons, the hypothetical statement, on a chemical basis, of probable differences between the iron precipitates from

[3] Private communication from G. G. Tunell, Jr., 3/25, "It is probable, according to Dr. Eugen Posnjak, Dr. H. E. Merwin and Professor T. W. Richards, that if moderate amounts of CuO are added to solutions of Fe_2O_3–SO_3–H_2O which are just saturated with $Fe_2O_3 . H_2O$ that $Fe_2O_3 . H_2O$ will precipitate."

the oxidation of chalcopyrite and pyrite, merits attention only as a stimulus to the observation of actual differences in the field.

Likewise, a field method deducing habits of difference between the oxidation products of chalcopyrite and pyrite seems distinctly more promising in limited pieces of ground than one undertaking to stretch such habits of difference over the variety of conditions occurring in a number of districts. Only after field evidence has proved the applicability of these habits over the larger areas, can they be safely used.

The field evidence has shown certain habits of difference to approach universality. There is actually a semblance of unity established through the study of large numbers of specimens, and a kind of proportionality in the combination of sulphur and bases during oxidation: the results suggest the range of field conditions to be more limited than one would expect. This does not mean that chalcopyrite and pyrite, upon oxidizing, always take one of the forms herein described; very often they take entirely different forms. But so far as revealed by field study, the forms described, irrespective of locality, always mean derivation from chalcopyrite, or pyrite, or other mineral specified.

The field study shows that where oxidation occurs in an inert environment, (1) pyrite usually leaves a void; (2) mixtures in which pyrite equals or predominates over chalcopyrite (molecular ratio) usually leave voids; (3) mixtures in which chalcopyrite considerably exceeds pyrite leave indigenous limonite; (4) as the chalcopyrite approaches purity, the iron of the indigenous limonite, though variable, approaches one-fourth to one-third that of the sulphide, the rest being removed. In inert gangue, even under the conditions most favorable for making a limonite pseudomorph after chalcopyrite, the pseudomorph is very porous.

In reactive gangues, the results, though less simple, still show intelligible features.

OXIDATION PRODUCTS DERIVED FROM CHALCOPYRITE AND FROM CHALCOPYRITE-PYRITE MIXTURES.

In Inert Gangues.

The type and principal kind of inert gangue is quartz. In such gangues, three types of limonite, formed as the oxidation products of chalcopyrite, have been established. They are classed as follows: (1) Coarse cellular; (2) fine cellular; (3) glassy, compact.

Coarse Cellular Type: This is characterized by a limonitic, siliceous boxwork or honeycomb with sharply defined, angular pattern. In many instances the cells show distinct parallelism of orientation. The cell walls are rigid and in part continuous in a straight line past several cells. Their thicknesses range from .02 mm. to .5 mm. The cell diameters vary from .2 mm. to 5 mm.

The coarse cellular limonite occurs mostly, though not exclusively, in a quartz or quartzose gangue. It is especially common where blebs and nodules of chalcopyrite have been leached from vuggy quartz, from quartz veins, and from fissured areas where quartz is the predominating gangue mineral. It is best developed where the original sulphide nodule was from one to ten centimeters in diameter. It has been observed but rarely where the original nodule was less than one half centimeter in diameter. (In the very small nodules the fine cellular type is more common.) In no case has the chalcopyrite, from which this type of limonite forms, been found without some admixture of pyrite. The molecular ratio is usually less than 1 *py* : 1 *cp*.

The development of the coarse cellular limonite was studied, under the microscope, in its various stages. In the primary sulphide, before oxidation has begun, minute white to glassy, hypogene silica veinlets are seen ramifying through the nodular mass. They mostly follow fractures with angular intersections within the sulphide nodule. Rarely they branch around individual sulphide grains. In some instances they cut across grains. In general, the veinlets are most numerous at the outer edges of the sulphide nodule, adjacent to the quartz gangue, and in the areas im-

mediately surrounding hypogene quartz grains within the nodule. They are rare or absent in the more finely fractured and purer sulphide portions of the nodule.

As oxidation of the chalcopyrite proceeds, the silica veinlets gradually advance their front and " eat " their way into the purer and less coarsely fractured portions, until a connected webwork extends throughout the sulphide mass, with unoxidized or only partly oxidized sulphide residuals filling the intervening spaces. But these extensions of the veinlets, instead of being the white to glassy, hypogene silica, are chalcedonic and clearly supergene; and instead of being pure silica, they consist in part of a hard, limonitic jasper. In some cases they consist wholly of the limonitic jasper without admixture of white silica. The supergene material not only makes extensions of the hypogene silica veinlets but also coats and in some cases replaces them. Distinct banding of limonite and chalcedony was observed in one specimen.

As oxidation of the chalcopyrite goes farther, the sulphide residuals within the webwork become completely oxidized, leaving behind the cellular honeycomb already described. In some cases the cell walls of this honeycomb mass are coated with a closely adhering, pulverulent limonite; in other cases the cells are completely empty. Where the cells are completely empty, the original sulphide nodules were found to carry a higher percentage of pyrite than did the nodules where pulverulent limonite remained.

(Where the original sulphide consisted wholly of pyrite, no cellular limonite was found, and the cavity usually was entirely free from limonite of any sort. The limonite sometimes occurred as a smeary paint on the eroded surface or along cracks around the cavity left by the oxidized sulphide, but more often was carried to the outer limits of the quartz gangue, before precipitation took place.)

The rigidity of the final cellular product resulting from the oxidation of the chalcopyrite, may be explained by the large proportion of silica in the cell walls. Its angularity, with frequent

parallelism of cell orientation, may be explained by the control of the cellular structure by fracture planes within the sulphide mass. The absence of pulverulent limonite in many of the cellular honeycombs may be explained by the original higher percentage of pyrite from which such products were derived, with the consequent greater acidity of the solutions, and the tendency for much of the iron to be carried away in solution.

Fine Cellular Type: This type of limonite frequently grades into the coarse cellular type. It differs from the latter, principally, in the following respects:

Size of cellular mass: The cellular mass is usually not more than two to three centimeters in maximum dimension. Often it is merely a speck.

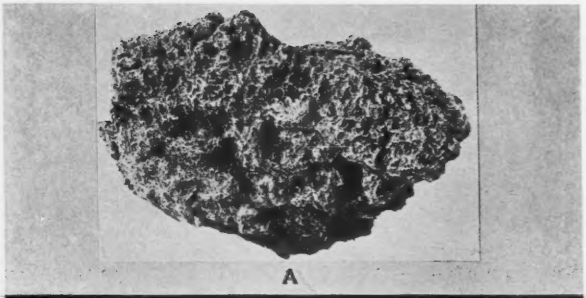
Size of cell: The cells range, in diameter, from less than .01 mm. to .5 mm. In some specimens the cellular structure is so fine that it cannot be recognized by the unaided eye. But no occurrences of this sort were found with the structure so fine that it could not be clearly distinguished under the hand lens. Such occurrences might conceivably exist.

Hypogene silica: Hypogene silica veinlets, either in the original sulphide or in the oxidation product, are rare and usually absent. The boxwork that exists consists almost wholly of limonitic jasper.

Rigidity: The cellular mass crumbles readily when light hand pressure is applied. Unless care is taken, it may fall out from a broken surface.

Lack of parallel orientation of cells: The cells do not usually show parallelism of orientation. For a given cell, the walls are rarely complete on all sides. Those that are complete, join at all angles the walls of other cells.

Pulverulent limonite: Most of the cell walls are thickly coated with fine grained, closely adhering, compacted, pulverulent limonite. Often the remaining cell space is partly filled with this product. Cells completely devoid of pulverulent limonite—such as are common in the coarse cellular type—are of infrequent occurrence. Where the cell structure is extremely fine, the limonitic



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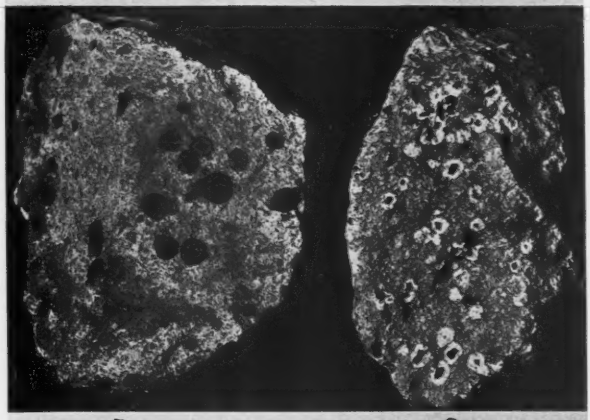

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A. Indigenous coarse cellular limonite derived from chalcopyrite that has oxidized in an inert (quartz) gangue. Dark portions, cellular limonite; light portions, quartz. The chalcopyrite from which this limonite was derived carried a slight admixture of pyrite. Note the resulting empty cells. Copper Creek, Bagdad, Arizona. Photographed for this paper by U. S. Geological Survey. 3/4 natural size.

B. Indigenous coarse cellular limonite derived from chalcopyrite that has oxidized in an inert (quartz) gangue. Dark portions, former chalcopyrite nodules; white portions, quartz. Limonite-free cavities in quartz represent former pyrite nodules. In two of the cavities a portion of the original pyrite nodule still remains. Los Aliados prospect, Sonora. 3/4 natural size.

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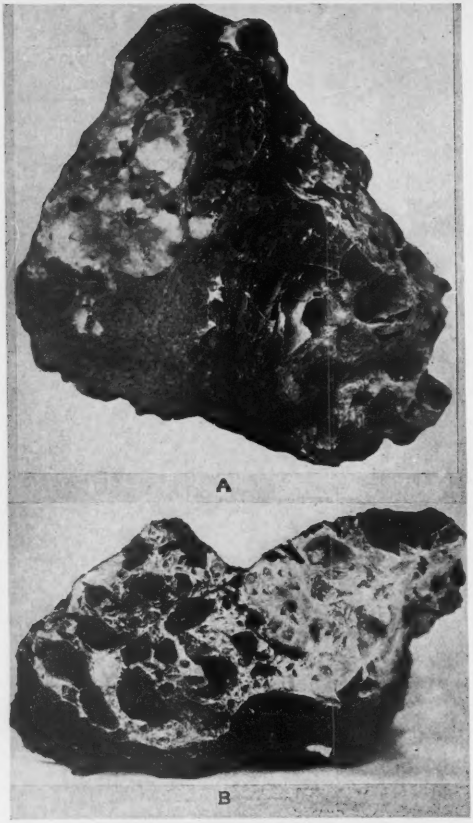

A. Indigenous coarse cellular limonite from massive pyrite, oxidized in a quartzose fissure in granodiorite traversed during oxidation by waters from a distant limestone area. Hanover Mountain, Hanover, New Mexico. Photographed for this paper by U. S. Geological Survey. 2/3 natural size.

B. Oxidation of pyrite in slightly kaolinized monzonite. Note limited development of inner bleached zone, strong development of limonite halo, and limited development of limonite "fog" or limonite stains because the solutions were effectively neutralized by the poorly kaolinized feldspars. Pyrite residuals still left. Niagara Gulch, Bagdad, Arizona. 2/3 natural size.

C. Oxidation of pyrite in well kaolinized monzonite. Note wide inner bleached zone, and almost complete absence of limonite halo. Most of the limonite has spread uniformly through the rock as a stain, or very thin limonite "fog," due to ineffective neutralization of the solutions by the highly kaolinized feldspar. Nearly the entire groundmass here is a "fog" area. Pyrite residuals still left. Alum Creek, Bagdad, Arizona. 2/3 natural size.

product may, therefore, appear to the unaided eye to consist entirely of the fine-grained, compacted, pulverulent limonite. The total iron left in the cavity as limonite from pure chalcopyrite usually represents from one fourth to one third the amount of iron of the original sulphide. It rarely exceeds one third. This amount decreases with increase in pyrite content of the original sulphide; until, when approximately equal molecular ratios of pyrite and chalcopyrite exist in the original sulphide, the cavity left upon oxidation is usually devoid of limonite.

Color: Of the various limonite types described in this paper, the fine cellular type is the only one with a characteristic color. Its color is deep ochreous (dark yellow orange). Other tints are occasionally met with, but the deep ochreous color is nearly universal.

Manner of occurrence: Although the fine cellular limonite occurs in quartz veins and quartzose gangues similar to the coarse cellular type, and is often coextensive with the latter, it more frequently occurs along fractures and as disseminations in altered igneous rock,—where the coarse cellular type has been rarely observed. In such rocks the walls of the fractures show silicification, due to the "flooding" by silica during hypogene mineralization; or, in the disseminated occurrences, there are small halos or "shells" of quartz, surrounding the chalcopyrite speck at the time of primary mineralization; so that, during oxidation, an inert gangue prevails.

The lack of rigidity in the fine cellular type of limonite as compared with the coarse cellular type may be ascribed to its greater proportion of very thin webs; to the incompleteness of its cell walls; to the lack of a regular cell pattern; and to the absence of a connected siliceous webwork. The greater abundance of pulverulent limonite within the cells may be ascribed to the fact that the chalcopyrite from which this type of limonite is derived usually contains less admixture of pyrite than that from which the coarse cellular type is derived. There is consequently lower acidity of the solution, and less tendency to export iron from the oxidizing sulphide.

Decrease in the ratio of pyrite to chalcopyrite with decrease in size of the sulphide bleb or nodule, although common, is of course not universal.

Chalcopyrite is not the only sulphide which, upon oxidizing, leaves indigenous cellular limonite. But, as between chalcopyrite and pyrite oxidizing in an inert environment, it is the only one ordinarily leaving it. Following the discussion of Exotic Limonites, is described a cellular limonite, not formed in an inert environment, derived from massive pyrite.

Glassy, Compact Type: Many varieties of the glassy, compact limonite are known. In this paper are discussed only two: limonite " varnish " and limonite " pitch."

Limonite " varnish " is made up of a " pile " of films of ochreous to dark brown limonite superposed one on another,—the lowest often resting upon unoxidized chalcopyrite, and consisting only of tarnish; the ones above constituting distinct films or layers of limonite,—with the entire " pile " rarely as thick as .5 mm. The individual film is often so thin that to the unaided eye it is indiscernible, and only the composite glassy, " varnished " mass can be distinguished. Under the hand lens the individual particles of the film have the appearance of very fine limonite grains deposited in a compacted mass directly at the sulphide source, without transportation in solution.

The " varnish " occurs mostly along fractures within nodules of massive chalcopyrite, or as coatings on disseminated chalcopyrite specks. It follows not only the formal fractures within the chalcopyrite but also those which are curved and irregular. It grows within the chalcopyrite body more erratically and less extensively than do the cellular types. It has not been thus far observed to come from any sulphide except chalcopyrite, and has not been observed in other than indigenous form.

On the one hand the " varnish " grades insensibly into the fine cellular limonite. On the other hand it grades into a glassy product, brownish-black to black in color. This is the limonite " pitch." The " pitch " usually coats sulphides undergoing oxidation, and spreads or " flows " out over their edges to coat and

replace the surrounding gangue. It is therefore less rigidly indigenous than the "varnish." It resembles and frequently grades into copper pitch.

In some districts the limonite "pitch" has been found unerringly to denote chalcopyrite; here it occurs in specks or nodules with residual cores of chalcopyrite, or not far away from similar specks or nodules having such cores. In other districts, or in other parts of the same district, it denotes cuprite. In still other places a limonite "pitch" resembling the chalcopyrite and cuprite derived products so closely that no criteria have been as yet established to distinguish it from the latter, has been found to originate in pyrite that carried little or no discernible admixture of chalcopyrite. Significant "pitch" types have not been differentiated; some of them at least are exotic limonites contaminated with kaolin, silica, manganese, limonite of other than chalcopyrite origin, and additional impurities.

Both the "varnish" and the "pitch" are distinguished from the black to iridescent iron oxide films commonly found where massive pyrite is undergoing oxidation; for they lack the submetallic luster, the smeary, painted appearance, and the finely nodular surface of the latter product.

Usually the "varnish," like the "pitch," occurs within a capping either in direct contact with, or within a few feet of, the sulphides, from which it comes, and where it does so, there is of course no necessity for interpreting it. Like the "pitch" it also tends to become obscured by, and to change into, other limonite types as oxidation of the sulphides becomes more thorough. But in some instances the "varnish" limonite has been found preserved in thoroughly leached capping many feet above known sulphides, and the ability to interpret it in such environments has proved useful. Compared to the cellular limonite, however, it is insignificant in point of volume, and less useful in the interpretation of croppings.

In Environments Containing Neutralizer.

The three types of limonite thus far discussed have been precipitated in inert gangues, and are indigenous. Typically, only air, water, and the elements that compose the sulphides have entered into the limonite-making reactions. Other things being equal, the sulphides, under such conditions, influence in an important way the nature of the resulting limonite products. And the limonite when indigenous under such conditions has the best chance of revealing its derivation.

Limonites precipitated in a reactive gangue may be indigenous, transported, or exotic.

In the transported and exotic limonites, precipitation does not occur until the iron-bearing solutions have left the limits of the sulphide body and entered the gangue. The resulting products, complicated by the addition to the reactions of substances other than air, water, and the elements that compose the sulphides, are far more difficult to interpret. Usually determination of the sulphide source, from the texture of the limonite alone, is impossible. But the distribution of the limonite from different sulphides may show significant variations. Thus pyrite, because the greater acidity of its solutions retards hydrolysis, has a tendency to send its oxidation products farther out into the rock than does chalcopyrite; and specimen evidence proves that, in the less strongly reactive gangues, this tendency is realized by certain zonal arrangements of the limonite products.

In the indigenous limonites precipitation must of course occur within the limits of the sulphide mineral no less in a reactive gangue than in an inert one. And insofar as the reactive gangue is prevented from taking part in the limonite-making reactions, the three types of indigenous limonite already described (coarse cellular, fine cellular, and glassy, compact) may form as readily in reactive gangues as in inert ones. On the other hand, in both kinds of gangue, neutralizer in solution, especially $CaCO_3$, may be brought within the limits of the sulphide bodies during oxidation, and cause precipitation of indigenous limonite where none otherwise would occur; or may cause precipitation of a greater

amount of indigenous limonite than would occur under normal air-water oxidation processes alone. Thus pyrite, oxidizing in an inert gangue and without the importation of neutralizer in solution, ordinarily does not leave indigenous limonite. On the other hand, well-defined limonite pseudomorphs after pyrite in a limestone gangue are often found. And a porous, pulverulent, indigenous limonite after pyrite that has oxidized in a quartz gangue, and where the gangue was traversed during oxidation of the pyrite by carbonate-bearing waters, is also rather common.

It is clear, therefore, that indigenous limonite may not necessarily mean copper; and if a given leached cropping is to be accurately interpreted, the indigenous limonite that means copper must be distinguished from that which has other derivation.

Rapid Neutralizer.—The type and principal kind of rapid neutralizer is calcite.

Most limonite precipitated by rapid neutralizer has a fluffy texture. This texture, so far as present observations extend, is the same for limonite precipitated by carbonate neutralizer, whether the original mineral is siderite, chalcopyrite, pyrite, or some other iron-yielding mineral,—and usually whether the limonite is indigenous or transported. Thus, this particular type of limonite does not by itself reveal its derivation; it reveals only the character of the precipitating agent.

The fluffy, pulverulent limonite may be distinguished from the indigenous, fine cellular limonite of determined chalcopyrite origin—which in its finer grained forms likewise is pulverulent—by the following physical differences: The fine cellular limonite of chalcopyrite origin adheres closely to the walls of the individual cells. It is a compacted limonite, with the particles slightly coalesced. Under the hand lens it has the appearance of being lightly glued to the cell walls. The fluffy, pulverulent limonite precipitated by rapid neutralizer, on the other hand, consists of loosely adhering particles in a highly porous mass which, under the mineral glass, looks as though it might be readily shaken off or blown away. In relief the particles resemble powdered sugar sprinkled over a surface.

This fluffy limonite, precipitated by rapid neutralizer, has three main origins: (*a*) indigenous after siderite and other ferruginous carbonate; (*b*) indigenous after sulphides; (*c*) transported; precipitated in gangue by neutralizer.

(*a*) In the limonites derived from siderite and other ferruginous carbonates, alteration usually has not proceeded far enough to obliterate the rhombohedral structure and the curved cleavage faces; and these features assist in identifying the original mineral. The presence of the rhomohedral cleavage faces in the pulverulent product does not necessarily, however, establish the limonite as of siderite origin. At Bisbee, large calcite crystals grow in earthy limonite, enclosing the limonite as an impurity and giving to it a rhombohedral cleavage. This product, upon oxidizing, cannot be distinguished from the oxidation product of siderite; and where oxidation has wholly destroyed the cleavage faces, the limonite in either case has not been distinguished from that derived from chalcopyrite or any other source, and precipitated by rapid neutralizer. But as has been already pointed out, its fluffy texture readily distinguishes it from the compacted pulverulent forms of the fine cellular limonite derived from chalcopyrite by air-water oxidation processes, even though both these limonite types are often similar in color.

(*b*) Limonite indigenous after sulphides and precipitated by rapid neutralizer is usually the same fluffy product as that derived from complete oxidation of siderite and ferruginous carbonates; but sometimes a very compact, almost glassy, variety occurs as pseudomorphs after pyrite. In a few instances the fluffy limonite has been observed superposed upon the compacted, finely cellular indigenous limonite of chalcopyrite derivation, especially in limestone gangues; but unless present in considerable amounts, reasonable doubt may be entertained as to which type of pulverulent limonite it belongs. The fluffy type, however, has been found in numerous places filling or partly filling the cubical pits left by oxidized pyrite—both in limestone gangues, and in quartz and igneous gangues traversed by carbonate waters—where no evidence of former copper in the vicinity could be found. An

outstanding example occurs at Bagdad, where at one place cubical pits in monzonite, left by leached pyrite, are completely filled with the fluffy limonite. No satisfactory evidence could be found at this particular place that the pyrite had been formerly enriched by chalcocite.[4] But the pits occur adjacent to a well defined fault, down which ground waters circulate freely from the overlying calcareous gravels. This suggests by actual field evidence that neutralizer, presumably as calcium bicarbonate, was carried in solution into the limits of the oxidizing pyrite, and precipitated the iron as the fluffy, indigenous limonite.

The various conditions affecting precipitation of indigenous limonite as compact pseudomorphs, such as cubes, and the reasons why it is in one case fluffy and in another case glassy, are not understood. Most frequently pseudomorphs after pyrite occur in limestone, and the presumption is, as already suggested, that $CaCO_3$ in solution during the oxidation of the sulphide served to neutralize the acid at the point of its liberation. In the field, wherever indigenous limonite occurred in a cavity left by oxidized pyrite—such as the case cited along a fault in the monzonite at Bagdad—or where more indigenous limonite was present in a cavity left by chalcopyrite than could be accounted for by air-water oxidation of the chalcopyrite, the writers have not failed to find evidence of the oxidizing sulphides being traversed, either continuously, or continuously during certain portions of the year, by ground waters that carried carbonates (usually $CaCO_3$) in solution.

[4] The flame test often shows copper to have been present in a cropping where other evidences are lacking; for a cropping from which copper has been leached, retains sufficient copper to be revealed in flame tests. The amount of copper retained increases very rapidly with the amount of neutralizer in the gangue, and often is independent of the original copper content of the sulphides. The entire absence of copper color in the test of numerous particles of the indigenous limonite in question is therefore good presumptive evidence that the particular limonite being tested was not derived from a copper source. The fluffy, pulverulent texture of the limonite in pyrite pits, and the absence of copper color in the flame tests, should not, however, at this stage of the croppings investigations, be taken as proof of sole pyritic origin of such limonite. It should be so accepted only if the other field considerations point convincingly to the same conclusions. This was the case along the fault noted at Bagdad.

It is of course impossible to establish from field conditions that all such limonite was precipitated by such means. The important consideration is that evidence of sufficient neutralizer in solution has been found to explain nearly all such additional indigenous limonite observed.

(*c*) Transported limonite, precipitated in a limestone gangue, is likewise usually of the fluffy type. To some extent the transported limonite forms as thin, rigid crusts; but such occurrences are rare except where there has been overwhelming acid attack during oxidation—as when massive pyrite oxidizes.

Where the oxidizing mineral is chalcopyrite, the limonite ordinarily replaces the limestone in immediate contact with the outer edge of the sulphide as fine grained, fluffy particles, usually closely packed together. Where the oxidizing mineral is pyrite, the same conditions obtain except that the limonite particles often are less closely packed near the sulphide contact, and for the same size sulphide particle the limonite in the case of pyrite may "spread" slightly farther outward into the rock. But there is not sufficient consistency in the contrast to serve as a basis for the interpretation of the limonites.

Summarizing, (1) Limonite precipitated by rapid neutralizer usually, but not always, has a characteristic fluffy texture, irrespective of the limonite's source. Its fluffy texture distinguishes it from the fine cellular, compacted, pulverulent limonite derived from chalcopyrite by air-water oxidation in an inert gangue, which it somewhat resembles.

(2) The fluffy limonite may be (*a*) indigenous after sulphides; (*b*) indigenous after siderite and other non-sulphide, iron-yielding minerals; (*c*) transported—precipitated by neutralizer in the gangue. Independently of other evidence, it does not in any of these cases reveal its origin either by texture or by distribution; it reveals at most only the character of the precipitating agent.

Moderately Slow Neutralizer.—Partly or wholly kaolinized feldspar is the most common of the moderately slow neutralizers; unkaolinized feldspar, because it lacks the porosity induced by kaolinization, is less effective.

Chalcopyrite and pyrite, in such a gangue, usually occur as disseminations, small blebs, or tiny veinlets along fractures. Upon oxidation they form both indigenous and transported limonite. The cavities left by chalcopyrite usually carry as much of the fine cellular and the glassy, compact types of *indigenous* limonite as do corresponding cavities in inert gangues, but generally do not carry as much of the fluffy, pulverulent limonite as do corresponding cavities in limestone. Cavities left by pyrite in a gangue of kaolinized feldspar usually carry little or no indigenous limonite of any sort.

In the *transported* limonite precipitated by the kaolinized feldspar gangue there is no significant difference in texture between that produced from chalcopyrite and that produced from pyrite.

But in such a gangue the transported limonite particles arrange themselves in more or less zonal patterns around the oxidizing sulphides, and the patterns formed from chalcopyrite and pyrite, respectively, possess certain general distinguishing characteristics.

Chalcopyrite, oxidizing in slightly kaolinized feldspar, when not surrounded by the silica " shells " and " floodings " mentioned previously, develops a zone of fluffy limonite replacing the feldspar and kaolin immediately surrounding the sulphide. The individual particles are more closely packed, and usually finer grained, than those ordinarily surrounding oxidized chalcopyrite in limestone. For convenience of discussion, the zone of closely packed particles is called the limonite halo.

The width of the halo is variable. Usually it is from one fourth to three fourths the diameter of the sulphide mass.

On its outer edge, the halo often grades rapidly into a limonite " fog," or rock stain, within a few millimeters of the chalcopyrite mass; but in some cases it ends abruptly, without development of " fog," against unstained feldspar. Kaolinization within the halo and the " fog " zone is but slightly more pronounced than in the unlimonitized feldspar portions of the rock beyond.

Where oxidation of the chalcopyrite is complete, a small amount of the fine cellular or the " varnish " limonite types may be left in the cavity, as already stated. Only rarely is any of the

fluffy, pulverulent limonite present, as is so often the case where oxidation occurs in limestone.

Pyrite, oxidizing under the same conditions in slightly kaolinized feldspar, also develops a limonite halo and an outer zone of limonite "fog." But the following differences are noticed between the chalcopyrite and the pyrite oxidation results:

1. Where oxidation is complete, the cavity formerly occupied by pyrite rarely contains limonite of any sort.

2. The limonite halo around the pyrite, instead of immediately surrounding it or the cavity left by it, is often separated from it by a narrow zone, 1 mm. or less thick, of thoroughly bleached rock. In many cases this inner zone is not wholly leached of iron; but when it is not, it usually carries sufficiently less limonite, per unit volume, to be distinguishable from the halo beyond.

3. The "fog" zone, in the case of pyrite, normally extends out into the rock farther than it does in the case of chalcopyrite. The distance is variable, but for the same size sulphide body 50 per cent. farther for the pyrite is not uncommon.

Where mixtures of the two sulphides occur, distribution of the oxidation products lies between the two zonal patterns described.

With increasing kaolinization of the gangue, the conditions above described are the same both in the case of chalcopyrite and of pyrite, or mixtures of them, as with slightly kaolinized feldspar, except that (1) the limonite is frequently finer grained; (2) the zonal boundaries are less well defined; (3) the "fog" zone commonly extends somewhat indefinitely farther out into the rock; (4) in the case of pyrite, the inner, kaolinized zone often contains nearly as much limonite, per unit volume, as the halo itself. In general, the distinctions between chalcopyrite and pyrite products in a well kaolinized gangue are less marked than in a slightly kaolinized one.

All variations from the ideal types above described, both for chalcopyrite and pyrite, have been observed; but the preponderant occurrences conform rather closely to these types.

The suggested explanation for the bleached or partly bleached

zone surrounding the pyrite cavity is that the more highly acid solutions from the pyrite carry the iron farther outward in the moderately slow reactive gangue before precipitation of limonite takes place, than do the solutions from the chalcopyrite.

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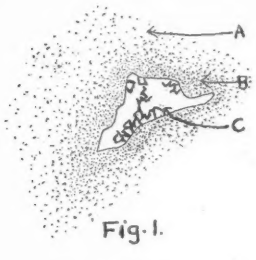

Fig. 1.

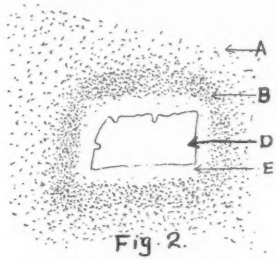

Fig. 2.

FIG. 1. Sketch showing characteristic oxidation of chalcopyrite in slightly kaolinized quartz monzonite. Cactus mine, Utah. ×10. *A*, zone of limonite "fog"; *B*, limonite halo; *C*, cavity with small amount of fine cellular limonite left by chalcopyrite.

FIG. 2. Sketch showing characteristic oxidation of pyrite in slightly kaolinized alaskite porphyry. Silverbell, Arizona. ×10. *A*, zone of limonite "fog"; *B*, limonite halo; *D*, empty cavity left by pyrite; *E*, inner, bleached, kaolinized zone.

In the case of a limestone gangue the same difference in acidity of the solutions may exist at the beginning, but neutralization is usually so rapid that, even in the case of pyrite, no bleached, inner kaolinized zone has a chance to form.

Very Slow Neutralizer.—Sericite is the most common of the very slow neutralizers.

In a sericite gangue—provided there is no kaolinization of the sericite, and no admixture, other than quartz, of unsericitized minerals—oxidation products form much as in an inert, or quartz, gangue. Nevertheless, both the halo and the "fog" zone beyond are usually feebly developed around the oxidized sulphide; but they are individually less extensive than those of the feldspar-kaolin gangues.

In a sericitized area, there usually remain certain amounts of

slightly sericitized feldspars, and of other moderately to strongly reactive neutralizers. As the proportion of these increases, or as the amount of kaolinization of the sericite increases, these various neutralizers react locally on the oxidation solution as in an environment composed of them, and the oxidation products approach more nearly in texture and distribution those peculiar to the predominating gangue mineral. The ordinary, impure sericite gangue, if it carried sulphides, therefore often contains products with heterogeneous physical characteristics and zonal arrangements.

Confusion of Zonal Patterns.—It has been shown that the zonal patterns left by the transported oxidation products of chalcopyrite and pyrite, respectively, in the moderately slow and very slow neutralizing gangues, have distinguishing characteristics, but that the limonites themselves, so far as texture and other physical qualities are concerned, as determined by field study alone, are indistinguishable. It has been shown further that the arrangement of the limonite particles in these zonal patterns is a function, not primarily of the particular sulphides involved, but of the sulphur-iron ratio of the solutions derived from oxidation of the sulphides.

It might be expected, therefore, that in an environment of moderately slow neutralizer (where disseminated deposits most commonly occur) the zonal pattern would be similar for a mixture of, say 2 *cp* : 1 *py*, as for a mixture of chalcocite and pyrite, or bornite and pyrite, or other sulphides, carrying the same proportions of sulphur and iron available for the limonite-making reactions.

The observed field facts confirm this expectation, and complicate the interpretation of leached croppings. While the respective zonal patterns left by the oxidation products of chalcopyrite and pyrite have proved to be valuable guides in determining the limonite's derivation where these two sulphides were the sole important iron-yielding minerals in the cropping, similar zonal patterns have been found in gangues of moderately slow neutralizer where the oxidizing sulphides were chalcocite-pyrite mixtures, or other sulphide combinations.

Without the testimony, then, of residual sulphides in the cropping to reveal the origin of the different patterns, or without the testimony of the *indigenous* limonites themselves, the nature of the original sulphides—whether chalcopyrite and pyrite, or other sulphide combinations—therefore is not inferrable from the zonal patterns alone.

There is hope, based on recent work, that the list of indigenous limonites proved characteristic of particular sulphides may be enlarged to include chalcocite and other sulphides. With the original sulphide definitely determined, the copper content of the material, represented by the leached cropping would be to some extent inferrable.

It should be reëmphasized, however, that in any case the application of the results is much safer if restricted to small areas, where the particular inferences can be checked, than when extended over several districts or even over several parts of the same district.

EXOTIC LIMONITES.

Less study has been applied to the exotic limonites than to the other types.

The exotic limonites embrace a large variety of the limonite "pitches" and jellies, and embrace also the fluffy, pulverulent and several cellular types (not described). The fact that these limonites often travel hundreds of feet before precipitation, suggests that in the solutions the ratio of sulphur to iron, and to other bases, is high. In turn, the high acidity suggests an abundance of pyrite at the source, but does not prove the absence of copper. So many substances may enter into the limonite-making reactions, however, and may so complicate the resulting product, that its history can be read less readily than that of the transported limonites, and far less readily than that of the indigenous limonites. It is doubtful whether in any case the full derivation of an exotic limonite can be with any certainty determined.

CELLULAR LIMONITE RESEMBLING THAT DERIVED FROM CHALCOPYRITE, BUT OF PYRITE ORIGIN.

As stated under "Fine Celluar Type," certain resemblances exist between the cellular limonites derived from chalcopyrite and those derived from other minerals. No attempt is made in this paper to enumerate or describe in full the determined types of cellular limonites of various origins that have been distinguished. But one type, often occurring as an oxidation end product of massive pyrite, is described because of its frequent association with the cellular limonites of chalcopyrite origin.

This type has not been observed where oxidation of the pyrite proceeded in an inert environment, but has been observed in some instances where massive pyrite was oxidizing in limestone, and more frequently where such pyrite along fissures in igneous rock was being traversed during oxidation by waters that had percolated through caliche, or that had traveled several hundred feet through igneous rock since leaving limestone areas. Although this cellular limonite is indigenous, it was not precipitated in an inert environment.

The product resembles a fine-celled sponge. Its chief points of contrast with the cellular types derived from chalcopyrite in an inert gangue are:

1. It possesses a spongy structure with rounded cell openings, as compared with the sharply defined, angular cell structure.

2. The cells occur erratically within the spongy mass, but maintain greater uniformity of size than do those derived from chalcopyrite, and do not usually attain diameters of more than 1 mm. to 2 mm.

3. The cell wall contains little or no silica or limonitic jasper.

4. The cell wall thickness usually shows abrupt variations, and in the thicker portions often equals the cell diameter.

5. Over portions of this mass there frequently occur thin, smeary crusts, and "painted" films of black or iridescent limonite.

Some of the contrasts between this oxidation product and the coarse cellular limonite derived from chalcopyrite, are brought out in Fig. A, Plate I and Fig. A, Plate II.

When once the points of difference between it and the cellular limonites of chalcopyrite origin are noted, the two are not readily confused.

LIMONITE COLOR.

It was stated previously that of the various limonites described in this paper, only one—the fine cellular limonite of chalcopyrite origin—showed any marked uniformity of color. The deep ochreous color of this limonite, while not invariable, is nearly universal, and is as pronounced in the moist climate at the Rocher de Boule mine in British Columbia as in the desert regions of Arizona and Mexico.

On the other hand, in the other limonites and especially in those left by pyrite, constancy of color was rarely observed, either in the same or different districts. The colors varied even in inert gangues; in gangues of rock neutralizer the color variations were nearly always pronounced. At Silverbell, for example, in the pyrite areas of the alaskite, the limonite has a general reddish color; in the pyrite areas of the alaskite porphyry, the limonite is finer grained, and has a general ochreous to buff color.

Color, in limonite, is determined largely by grain size and state of aggregation. A reddish or orange limonite ground sufficiently fine becomes ochreous. Ground still finer, it becomes yellow.

A good many different conditions, such as the rapidity of neutralization; or, in inert gangues, variation in the acidity of the solutions; or, in the case of well kaolinized feldspar gangues, such variations plus the effects of adsorption; would affect grain size, and consequently affect color of the limonite. And on this account, any approach to uniformity in color over extensive areas, as in the case of the fine cellular limonite, is a matter for surprise.

SPECIFIC APPLICATIONS OF THE CRITERIA PRESENTED.

Following is a table giving four applications of the criteria for the determination of the original minerals from the texture, or the distribution, or both, of the derived limonite:

	Maximum Dimension of Cavity or Cellular Mass.	Variety of Limonite.	Structure of Limonite.	Gangue.	Distribution of Limonite with Respect to Cavity.	Inferred Source of Limonite.
1.	2.25 cm.	Indigenous	Fine cellular, sharply defined, angular pattern. Cell walls very thin and fragile; chiefly jaspery limonite. Size of cells, less than .5 mm. diameter. Compacted, pulverulent limonite adheres closely to cell walls and bottoms. Some of cells empty. Cells break down when lightly pressed.	Quartz	Cellular limonite wholly within the cavity. Thin films of faintly iridescent limonite on quartz several cm. from cavity.	Chalcopyrite nodule containing very small admixture of pyrite.
2.	4.6 cm.	Indigenous	Spongy, cellular mass. Cell diameters less than 3 mm. General uniformity of cell size. Cell wall thicknesses are greatly variable and in places equal cell diameters. No jaspery limonite. Iridescent films on parts of spongy mass.	Mostly quartz	Occurs in slightly silicified fissure zone in feldspathic rock, traversed by surface waters that have percolated through caliche ($CaCO_3$).	Massive pyrite, which has oxidized in an environment of moderately rapid neutralizer.
3.	1.8 mm.	Transported	Compacted pulverulent to granular. A few flakes of very fine cellular limonite clinging to cavity wall.	Slightly kaolinized feldspar	Around cavity is discontinuous bleached zone, .2 mm.–.4 mm. thick, well kaolinized. Outside this is halo of closely packed, fine grained, fluffy pulverulent limonite 1.5 mm. thick. "Fog" zone beyond, 2 mm.–3 mm.	Chalcopyrite containing slight admixture of pyrite, oxidized in moderately slow reactive gangue.
4.	3.5 cm.	Indigenous	Loosely adhering, fluffy pulverulent limonite. Occasional indistinct rhombohedral, flaky structure discernible.	Quartz	Limonitic mass fills the cavity.	Siderite, or other ferruginous carbonate.

SUMMARY.

A. Indigenous Limonite.

1. Chalcopyrite, oxidizing in an inert environment, usually leaves one fourth to one third its iron in the form of indigenous limonite.

2. Pyrite, oxidizing in an inert environment, usually leaves no indigenous limonite.

3. A mixture of 1 *py* : 1 *cp* (or greater proportion of pyrite), oxidizing in an inert environment, usually leaves no indigenous limonite.

4. If indigenous limonite is left by a mixture of 1 *py* : 1 *cp* (or greater proportion of pyrite), or if more than one third the iron of chalcopyrite is left as indigenous limonite, the influence of a soluble precipitant, especially $CaCO_3$, is suggested.

5. Of the indigenous limonites, three distinct types produced by the oxidation of chalcopyrite in an inert environment have been identified and described. They are the coarse cellular, the fine cellular, and the glassy, compact "varnish" types.

6. The physical qualities of these limonites serve to distinguish them from limonites of somewhat similar appearance but of other origin.

B. Transported Limonite.

7. Transported limonite, by its physical quality, does not reveal its derivation. But, in particular environments, its state of aggregation and its position with reference to the oxidized sulphide, give limited information regarding its derivation.

8. The state of aggregation and the position of the limonite with respect to the original sulphide do not show significant differences between chalcopyrite and pyrite in environments of rapid neutralizer, such as limestone; but in environments of moderately slow neutralizer, such as kaolinized feldspar, they do show such differences. Where the feldspar is strongly kaolinized the differences are less marked.

9. The zonal pattern, or position of the limonite with respect to the original sulphide, formed in any particular case, varies with

the sulphur-iron ratio of the original sulphides. Where those sulphides are known to consist preponderantly of pyrite and chalcopyrite, or of chalcopyrite only, the former copper content of the leached zone is in some degree inferrable.

C. Exotic Limonite.

10. Exotic limonite suggests a high ratio of sulphur to iron and other bases. It suggests relatively abundant pyrite, but does not prove the absence of copper. Its history can be read less readily than that of transported limonite, and far less readily than that of indigenous limonite.

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FRACTIONATION OF PETROLEUM DURING CAPILLARY MIGRATION.[1]

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In an earlier paper [2] the writer has described a simple apparatus for the study of the capillary relationships of petroleum and water. In that paper it was indicated that movements had been observed over a period of several years. However, it was not stated that these long periods of observation had been made possible by the use of a modified form of the apparatus, which permitted of a continuous supply of water. The use of this modified form of the apparatus has given some very interesting results; the most prominent of which is an apparent fractionation of the petroleum during the migration of the petroleum and water.

The modified form of the apparatus (Fig. 1) may be described as follows:

Instead of using glass tubing as in the original design of the apparatus, a test tube is used. It is drawn out to a capillary tube in the middle as before, but has only one end open for the introduction of sand or clay as the requirements of the experiment may demand. The bulb at the sealed end of the tube is filled with distilled water by exhausting the air and allowing the water, which has been placed in the open portion of the tube, to flow into the closed part until all of the air is excluded and the capillary tube is filled with water. A mixture of petroleum and sand or petroleum and clay is then introduced into the open end and lightly packed by closing with a cork. The cork is not fastened and, owing to the lubrication of the tube by the petroleum of the mixture, it is not capable of exerting a back pressure upon the petroleum as the result of the movement of water into the sand.

[1] Presented before Society of Economic Geologists, New York, May, 1925.

[2] "Study of Capillary Relationships of Oil and Water," Econ. Geol., vol. XVIII., pp. 167–172, 1923.

The cork is used merely to prevent evaporation of the lighter constituents of the petroleum. That it has no effect other than this has been demonstrated by leaving some of the tubes uncorked, the only observable difference being a shortening of the time during which the capillary movement would continue.

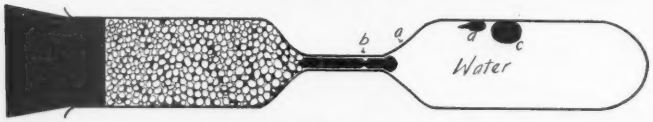

FIG. 1. Modified type of apparatus. (For original design see ECON. GEOL., vol. 18, 1923, p. 168.)

In one tube of this design, in which the movement has now been going on for nearly four years, a series of events has happened which has suggested the title of this short paper. At first, as the petroleum was forced out into the water reservoir by the capillary movement, it was deformed up the slope of the tube at *a*, Fig. 1, by the difference in specific gravity of the petroleum and water until it would separate and form a globule (*c*, Fig. 1) at the top of the tube. Periodically these drops would separate and coalesce with this globule. Subsequently a slowing down of the movement was noted, so the time between the liberation of drops became longer and longer until after a period of about two years the movement appeared to have almost ceased. However, after a period of about six months another drop was released.

This drop behaved altogether differently than the earlier ones. First, it did not separate at the end of the capillary tube, but back within the tube at *b*, Fig. 1. Second, when liberated, it did not assume a spheroidal form but retained the original attenuated "tail" (*d*, Fig. 1) which resulted from the separation within the capillary tube. Third, this unspherical drop, which has a form similar to a Prince Rupert drop, has not coalesced with the larger globule. Further, considerable shaking has failed to make them unite or change the form of the misshapen drop.

Over a year has passed since this misshapen drop separated and now evidence of the separation of another drop is beginning to manifest itself by a narrowing of the oil column within the capillary tube at *b*, Fig. 1.

Although it has not been possible to remove the globule and misshapen drop and demonstrate by means of a chemical analysis, that fractionation of the petroleum has taken place, the writer believes that the difference in viscosity between the two is ample evidence that it has occurred. That is, the lighter constituents of the petroleum have moved more rapidly than the heavier or more viscous constituents and produced a segregation of those constituents.

As far as I am aware, the idea of fractionation under the influence of capillary forces has not appeared in print. If the idea has been suggested, I am certain that this is the first direct experimental evidence offered in support of the idea. Further, I should like to suggest that this action may explain, at least in certain cases, the not infrequently observed fact of the variation in composition of the petroleum in different parts of the same pool.

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A NEW KIND OF METAMORPHISM AND ITS APPLICATION TO THE STUDY OF ORE DEPOSITS.

A. N. WINCHELL.

TWENTY years ago Van Hise [1] pointed out that the various kinds of metamorphism then recognized, such as thermo-metamorphism, hydro-metamorphism, chemical metamorphism, static metamorphism, pressure metamorphism, dynamo-metamorphism, regional metamorphism and contact metamorphism, were not mutually exclusive nor supplementary, but many of these features were present in practically every concrete case of metamorphism in nature. He therefore proposed that metamorphism be classified under two types which he named katamorphism and anamorphism, showing clearly that in their nature these two types are mutually exclusive and complementary.

Van Hise pointed out also that metamorphism is a result of the tendency of matter to reach conditions of stability, both physically and chemically. Evidence seems to be available at present to show that chemical and physical forces do not always act together in causing changes to more stable substances or groups of substances; on the contrary, chemical forces may produce changes which mean a marked decrease in physical stability, just as physical forces may produce changes which involve a decrease in chemical stability.

When external physical and chemical conditions cause feldspar to change completely to sericite or kaolinite, or pyrite to change wholly to limonite or hematite, evidence that the change has occurred may be entirely lost; if some evidence is found it is usually a result of careful study coupled with some fortunate accident, such as the preservation of former crystal forms by pseudomorphism. Therefore changes which are incomplete in some way are especially instructive.

[1] Treatise on Metamorphism, U. S. G. S. Mon. XLVII., 1904.

It has long been known that crystal structure may change completely without change of chemical composition: These changes may be regarded as of two different types, one, which leaves no visible or known evidence of the former condition, illustrated by the change of massive aragonite to calcite, and another, which commonly produces results that may be recognized as a product of the change, illustrated by the change of high to low temperature quartz. These last-named changes are very useful in giving some knowledge of the physical conditions of temperature and pressure to which the substance has been subjected.

The new idea which is here presented is that chemical changes are also possible in some cases without destruction of crystal structure, and that some of these changes may be used to obtain some knowledge of the chemical conditions, and particularly the nature of the solutions, to which the substance has been exposed. These changes are also of two types, one being of such a nature as to leave no evidence that it has occurred, and the other being of such a nature as to leave unmistakable and very plain evidence of its presence. It is, of course, chemical changes of the second type which are useful in giving some knowledge of the chemical nature of the solutions with which the substance has been in contact.

When a crystal of plagioclase, growing in a dry melt, changes composition from bytownite to andesine or from labradorite to oligoclase, the change of composition is accomplished without change of crystal structure and no evidence of the change can be obtained from the final product. In a similar way a crystal or mass of siderite can doubtless be changed in nature to magnesite or to rhodochrosite without leaving any evidence of the former composition. Such changes are confined always to a single isomorphous system, and are not useful in shedding light on the chemical nature of the solutions which accomplished the change because there is no way to recognize that the change has occurred, since the final product could be produced by natural processes without passing through the earlier stage, as, for example, by direct precipitation from solution.

However, other chemical changes occur, without destruction of the crystal structure, which produce products that are easily and certainly recognizable as derived from the former substance, since they can not be produced without passing through that stage. For example, a crystal of biotite immersed in sulphuric acid loses all its components except SiO_2, and yet this SiO_2 retains the approximate structure and optical properties of the original mica. Again, a crystal of heulandite can be deprived of all its constituents except SiO_2 (by treatment with HCl) and this SiO_2 (especially after heating) shows definite optical agreement with the original heulandite.[2] In a similar way, stilbite [2] may be forced to yield a residue of SiO_2 which is optically analogous to that zeolite. Or again, brucite,[2] $Mg(OH)_2$, when properly heated loses H_2O, but without assuming the properties or structure of periclase (MgO); on the contrary, the heated brucite retains approximately its own structure and properties even though its composition has been changed. The calcium rare-earth carbonate called parisite gives similar results when heated. X-ray studies of brucite and parisite before and after heating indicate that such drastic changes as illustrated in these cases do not occur without producing some effects on the crystal space-lattices, but these suffer a certain amount of bending without loss of identity or substantial change of character.

Of course such changes as just described are unknown in nature and therefore are of no use as indicating the chemical nature of natural solutions in a given region. The writer believes that certain changes of composition which do occur in nature are of the same kind as those described. He has discussed two instances in recent articles.[3] In one case he has given the evidence to show that zeolites (*as first formed*) vary in composition in the same way as feldspars, namely, a given point in the space-lattice may be occupied by Ca or by Na, and increase of Na is accompanied by a simultaneous increase of Si at the expense of Al. It is well known that (*after their formation*) zeolites change composition

2 F. Rinne, "Crystals and the Fine-Structure of Matter," 1924, pp. 143–157.

3 "A New Theory of the Composition of the Zeolites," *Am. Mineral.*, X., 1925. "Chlorite as a Polycomponent System," *Am. Jour. Sci.*, 1925, in press.

easily and rapidly under the influence of varying solutions with which they may be in contact, in such a way that a sodium zeolite in a solution of $CaCl_2$ changes to a calcium zeolite by exchange of 2 Na for Ca, and changes back again if then immersed in a solution of NaCl. This change of composition (after formation) is unlike the possible variation of composition when first formed, and may therefore be recognized. When discovered, it leads to an inevitable conclusion regarding the character of the solutions in which the zeolite was last immersed, as well as giving a clue as to the character of the solutions from which it formed.

In another case the nature of the chemical change is different. Evidence is available which points to the conclusion that in ferriferous chlorite, and presumably in other hydrous silicates which contain iron, the state of oxidation [4] of the iron may change without destroying or materially changing the crystalline space-lattice. This, also, is a change which is only possible after formation of the crystal, and therefore indicates the activity of reducing or oxidizing solutions.

Such changes constitute a type of metamorphism which is "new" in the sense that it is characterized by a feature which has not been recognized hitherto in nature. This feature is the change of composition without destruction of the crystalline space-lattice.

At the present time this conception is to some extent hypothetical; if correct, it seems to the writer that it will surely be useful in the study of ore deposits, and it is therefore presented in the hope that it may be tested as soon as possible, and perhaps in various ways. For example, if an ore deposit contains ferriferous chlorite, an analysis of that mineral should yield indications of a change in the oxidizing or reducing character of the solutions which have affected the deposit since the formation of the chlorite, if such a change occurred while the solutions were still warm or hot. Recent experiments indicate that cold solutions are not effective agents in producing such changes in chlorite.

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[4] See *Science*, vol. LXII, 1925, p. 311, for proof from an unexpected source that the state of oxidation of iron in magnetite may be changed without destroying or materially changing the crystalline space-lattice.

GEOLOGY OF THE ETTA SPODUMENE MINE, BLACK HILLS, SOUTH DAKOTA.

G. M. SCHWARTZ.

INTRODUCTION.

THE Etta mine is known the world over as a deposit containing huge crystals of spodumene, undoubtedly the largest thus far discovered anywhere. It is also worthy of note that it is, at present, the most important producer of lithium ore in the United States. Although the mine has been repeatedly referred to, and briefly described, no complete description has appeared since the large openings made by war production. This paper is based on a field study made during brief visits to the region in 1921, 1922, and 1924, and on subsequent studies in the geological laboratory of the University of Minnesota.

Acknowledgments are due to Mr. James Cessna, Superintendent of the Etta, for permission to study and map the mine and for many mineral specimens. I am especially indebted to Mr. R. J. Leonard for much assistance in the field and analytical work.

GENERAL FEATURES.

History of the Mine.—Previous to 1883 the Etta claim had been worked for mica. In that year Mr. W. P. Blake[1] determined tin in samples from the Etta mine which had been submitted to him for analysis. In 1884 the claim became the property of the Harney Peak Tin Mining, Milling, and Manufacturing Company, but the company later failed. After some years the Etta property was leased for mining spodumene, and production apparently began in 1898,[2] continuing more or less actively

[1] Blake, W. P., "The Discovery of Tin-stone in the Black Hills of Dakota," *Eng. and Min. Jour.*, vol. 36, pp. 145–6 and 163–4, 1883; "Tin Ore in the Black Hills of Dakota," *Min. Res. of the United States*, 1883–4, pp. 602–613.

[2] O'Harra, C. C., "Mineral Resources of South Dakota," Dakota Geol. Survey Bull. 3, 1902. Also South Dakota School of Mines Bull. 6, 1902.

for five or six years and then only intermittently until the world war increased the demand for lithium. In 1909 Hess [3] reported that the Standard Essence Company of Maywood, New Jersey, had worked the deposit for some years. During the war, mining was active and a large area of the deposit was exposed. Since the war, mining has been continuous, but not particularly active. The mine is now controlled by the Maywood Chemical Company of Maywood, New Jersey.

The Mine.—Until the past year all of the mining was by open pit methods although a tunnel had been run at depth to test the extension of the deposit and also for drawing ore from the pit. Recently operations have been started underground in a stope above the lower tunnel and the small production is coming from this stope. The rock is blasted and the spodumene sorted by hand picking. The waste, consisting principally of feldspar and quartz, is dumped as much as possible in piles composed of one mineral. Early in 1924 some of the feldspar dumps were being sorted and the feldspar shipped to Chicago. Small amounts of columbite and other minerals are also sorted and sold when there is a demand.

Location and Topography.—The Etta mine is located about a mile south of the village of Keystone, Pennington County, South Dakota, at an elevation of 4,500 feet above sea level, and six miles northeast of Harney Peak, the highest point in the Black Hills. (Elevation 7,240 feet above sea level.) The Hermosa topographic sheet of the United States Geological Survey shows the location of the mine and its relation to the surrounding country. It is situated on a knob between two gulches which join just below. (See Plate A, Bull. 6, S. D. School of Mines.) The surrounding country is very rugged, the granites and pegmatites forming hills and mountains. The Black Hills branch of the Burlington railroad passes through Hill City, ten miles to the west, and a spur extends to Keystone.

Previous Descriptions.—So many papers have referred, at least briefly, to the deposit that only the more important are

[3] Hess, F. L., *Min. Res. U. S.*, 1909, vol. 2, p. 651.

listed here. The first and most complete descriptions were by Blake.[4] Later Headden,[5] Hess,[6] and Ziegler[7] added much data. Runner and Hartman[8] have more recently noted some features in connection with the occurrence of tungsten in the pegmatites of the region.

ASSOCIATED ROCKS.

The Harney Peak Granite.—The spodumene of the Etta mine occurs in one of a great series of pegmatites found in the area surrounding the Harney Peak granite which forms the core of the Black Hills uplift. No map has been published which gives the outlines of this granite mass in detail, but Newton[9] shows it as having a roughly oval outline of about seven by ten miles. These certainly are maximum dimensions since much of the area outlined is known to be occupied by pre-Cambrian schists in which the granite is intruded. It is classed as pre-Cambrian by all investigators who have mentioned its age.

The parts of the granite seen by the writer are largely pegmatitic. Schist inclusions of all sizes are abundant even on Harney Peak, the center of the granite area. This indicates that the granite is the upper part of a batholith. Ziegler[10] has stated: "The high acidity, the presence of the minerals characterized by the mineralizers, the coarseness in grain, and the variability in the mineral makeup, as well as geological conditions, seem sufficient proof to the writer that the exposed portions of the granite

[4] *Op. cit.*

[5] Headden, W. P., "Note upon the Discovery and Occurrence of Tin in the Black Hills," *Proc. Col. Sci. Soc.*, vol. 3, pp. 347–350, 1890.

[6] Hess, F. L., "Tin, Tungsten, and Tantalum Deposits of South Dakota," U. S. Geol. Survey Bull. 380, pp. 131–163, 1909; *Min. and Sci. Press*, vol. 100, p. 822, 1910.

[7] Ziegler, V., "The Minerals of the Black Hills, South Dakota," South Dakota School of Mines Bull. 10, 1914; *Min. and Sci. Press*, vol. 108, pp. 604–8, 654–6, 1914.

[8] Runner, J. J., and Hartman, M. L., "The Occurrence, Chemistry, Metallurgy, and Uses of Tungsten," South Dakota School of Mines Bull. 12, 1918.

[9] Geological map of the Black Hills, 1879. But see U. S. G. S., folio No. 219 (in press).

[10] Ziegler, V., "The Differentiation of a Granitic Magma as shown by the Paragenesis of the Minerals of the Harney Peak Region, South Dakota," ECON. GEOL., vol. 9, pp. 264–277, 1914.

represent only the marginal zone of a granite batholith, probably its upper zone laid bare by erosion."

Ziegler describes the granite as soda rich, high in quartz and muscovite, with orthoclase, microcline, and albite, as the chief feldspars. He took a special phase from near Custer as representing most closely the Harney Peak magma. It is characterized by alkali feldspars, biotite, muscovite, and about 8 per cent. quartz. The accessory minerals in the order of their importance are: apatite, zircon, magnetite, and titanite.

The writer collected two specimens which seemed to him to represent most nearly normal granite phases. The first, from the top of Harney Peak, is a granite with a medium to fine texture, and many black needles of tourmaline. Microcline and oligoclase feldspar, with microcline predominating, make up about 60 per cent. of the rock. Quartz, with accessory tourmaline, muscovite and garnet compose the remainder. The tourmaline is blue, varying to nearly colorless. The second rock was obtained from a road cut between Hill City and Sylvan Lake. It is a gray, medium-grained rock with from 60 to 65 per cent. oligoclase and microcline, about 25 per cent. quartz and 5 per cent. each of biotite and muscovite. An occasional pink garnet is the only accessory.

The Schists.—The Harney Peak granite is intruded in a series of pre-Cambrian metamorphic rocks which show considerable variation. Ziegler[11] has noted the following types near the granite: phyllites, mica schists, staurolite schists, actinolite schists, garnet schists, tourmaline schists, graphite schists, mica gneisses, amphibolites, and quartzites.

The Etta pegmatite is intruded in a rather fine-grained gray schist consisting principally of quartz and biotite with occasional grains of garnet, muscovite, and tourmaline. At places not far from the mine large staurolite metacrysts are found in a schist which otherwise appears like that just described.

At the contact of the pegmatite and schist the latter has been intensely altered in a zone averaging 5 feet in thickness. (See Figs. 1 and 2.) A detailed study of this metamorphism must

[11] Ziegler, V., ECON. GEOL., vol. 9, p. 265.

be left for a later paper, but some of the features may be outlined here. The schistosity is, for the most part, destroyed and a granular sugary rock developed which shows variations from place to place around the periphery of the pegmatite. As a rule the contact is sharp between the pegmatite and the intruded rock which grades from the sugary phase to the normal schist. However, at places there is an alteration of pegmatite and contact rock or schist. The most striking phase of the contact rock consists of biotite plates as much as two inches across embedded in a gray sugary matrix of quartz, microcline, plagioclase, garnet, muscovite, and tourmaline. Quartz and microcline are abundant and enclose the other minerals noted. The biotite and tourmaline are especially noteworthy as they were not observed within the pegmatite proper. Along the east wall of the pit a tourmaline schist is especially abundant. The principal mineral is tourmaline. Quartz is abundant and is embedded in a matrix or network of tourmaline forming a mosaic. A common phase is a fine granular rock consisting of quartz and feldspar with minor amounts of tourmaline, garnet, and muscovite.

The contact action is remarkable for its intensity over a zone which is so narrow and grades quickly to schist which is little different from that at a considerable distance from any exposed intrusive. The small size of the pegmatite makes the severe effect the more remarkable but the highly pegmatitic nature of the mass doubtless offers the explanation.

Distance of Pegmatite from Granite.—Time did not permit a detailed study of the east side of the batholith to determine the exact boundary, but a large mass of granite stands at a considerable elevation about one and one half miles west of the Etta mine. This is roughly the horizontal distance of the mine from the exposed granite, but the abundant pegmatite masses of various types and shapes indicates that the granite may not be far below in the region of the mine. From a distance, outcrops near the mine appear to be granite, but on close examination they are found to consist of coarse pegmatites.

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THE PEGMATITE.

General Relations.—The pegmatite which forms the Etta deposit is one of a great series which are distributed on all sides of the Harney Peak granite. Of these the group at Keystone is perhaps the greatest. These pegmatites and their minerals have been described in considerable detail by Ziegler [12] and Hess.[13] The mines have produced on a commercial scale: lithium (in the form of spodumene, amblygonite, and lepidolite), tungsten, mica, rose quartz, feldspar, beryl and small amounts of tantalum and columbium incidental to other mining. Tin has been the cause of more explorations than those noted, but thus far little has been produced.

The Etta pegmatite is not connected at the surface with other pegmatites but they are found on all sides near it, the Hugo mine pegmatite being only 1,000 feet to the west.

Size and Shape.—The pegmatite is roughly oval in outline with diameters at the plane of the lower tunnel of 200 and 250 feet, with a pronounced indentation on the east side due to a mass of schist. The pegmatite extends 125 feet above the lower tunnel, but was much higher before being destroyed by mining. Figs. 1 and 2 show the form of the deposit in plan and cross-section. Diamond drill holes have been put down from the lower tunnel and indicated that the deposit closes in about 100 feet below. It seems unlikely that the pegmatite ends entirely at this depth, but will probably have at least a small connecting dike beneath.

Structure and Texture of Pegmatite Mass.—Of the repeated descriptions of the Etta deposit only one has ever shown a sketch of the structure of the mass. This was by Blake [14] in one of the

[12] Ziegler, V., "Lithia Deposits of the Black Hills," *Eng. and Min. Jour.*, vol. 96, pp. 1053–1056 and 1088, 1913; "The Mineral Resources of the Harney Peak Pegmatites," *Min. and Sci. Press*, vol. 108, pp. 604–608 and 654–656, 1913; "The Minerals of the Black Hills," South Dakota School of Mines Bull. 10, 1914.

[13] Hess, F. L., "Tin, Tungsten, and Tantalum Deposits of South Dakota," U. S. Geol. Survey Bull. 380, pp. 131–163, 1909; *U. S. Min. Res.* for 1909, pp. 649–653; "Lithium and its Sources," *Min. and Sci. Press*, vol. 100, pp. 822–824, 1910.

[14] Blake, W. P., "Tin Ore in the Black Hills of Dakota," *Min. Res. of the United States* for 1883–1884, pp. 602–613.

earliest articles. His sketch showed four zones as follows, beginning with the outer: (1) Biotite and muscovite, (2) crystals of spodumene, greisen and tin-stone, (3) greisen and tin-stone, (4) quartz and feldspar. This referred to the upper part of the knob and does not apply to the deposit as now exposed.

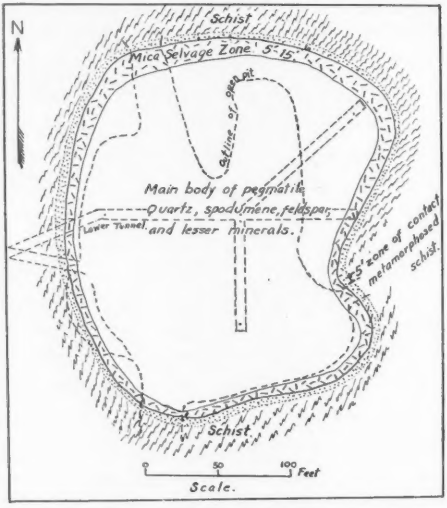

FIG. 1. Plan of the structure of the Etta pegmatite at the level of the lower tunnel.

As previously noted, the schist at the contact is much altered to a coarse sugary rock which at places contains coarse biotite, and other places much tourmaline. Undoubtedly the schist is much changed by additions from the pegmatite but the apparent absence of biotite in the pegmatite proper suggests to the writer that at least the iron of the biotite came from the schist. This occurrence of the mineral may account for Blake's statement that it occurred in the outer zone. The outer zone of the pegmatite is normally five or more feet thick, but rarely, if ever, over fifteen. It consists principally of muscovite with quartz and some feldspar. It has been described[15] as approaching the composi-

[15] Ziegler, V., *Eng. and Min. Jour.*, vol. 96, p. 1053, 1913.

tion of a typical granite. This seems misleading as muscovite is by far the most important mineral and feldspar is subordinate to quartz. The writer has adopted the phrase "mica selvage zone" as conveying the idea of the nature of this material. This outer zone grades quickly to the main body of the pegmatite

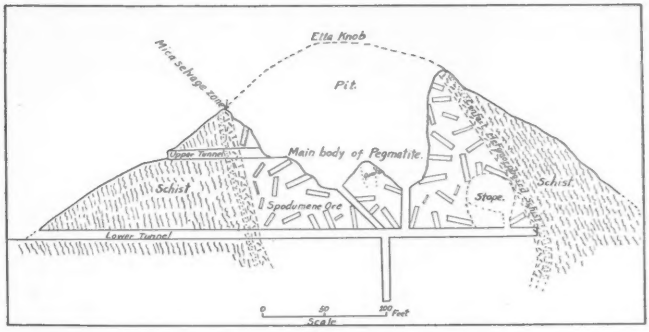

FIG. 2. Cross-section of the Etta pegmatite along line of the lower tunnel.

within which no definite zoning can be distinguished at present. This main body is made up of an extremely coarse mass of quartz, feldspar, and spodumene with lesser amounts of muscovite, lepidolite, beryl, columbite, lithiophylite, and other minerals. No regularity is discernible. Huge crystals of spodumene resembling logs lie in every direction. These vary in size from a foot or two in length to thirty and even forty feet. The largest recorded was forty-two feet long, from three to six feet in diameter, and contained thirty-seven tons of spodumene. At places now well exposed on the south wall of the pit are star-like aggregates of spodumene crystals radiating from a center which is often a mass of muscovite. Normally the spodumene crystals are embedded in masses of milky quartz and imprints of the crystal faces are left when the spodumene is removed. The crystals often cross and one is cut and somewhat altered at the intersection, indicating that the later crystal had grown through the earlier. Alteration is common at these intersections. At places

are masses of quartz and feldspar, or quartz alone, practically free from spodumene. These barren areas, however, are apparently not confined to a definite zone, but are in the nature of horsts.

MINERALOGY.

The number of minerals listed as occurring in the Etta mine is very large, but many are rare and can not be observed by a casual visit. The principal minerals are: spodumene, quartz, feldspar (albite, microcline, and oligoclase), and muscovite.

ANALYSES OF MINERALS FROM THE ETTA MINE.

	1	2	3	4	5	6	7	8	9	10
SiO_2	62.91	63.79	66.65	44.87	44.23	1.00				2.00
Al_2O_3	28.42	20.13	21.51	36.77	37.49	n.d.				
Fe_2O_3	.53	.22		1.70	1.60	1.80				
FeO	n.d.	n.d.	n.d.	n.d.	n.d.		8.28	8.59	8.33	7.30
MgO	.13	.38	.08	.72	.18					
CaO	.11	.25	.05	.10	.08		.88			
Na_2O	.46	2.39	10.42	.60	.68					
K_2O	.69	12.55	.71	10.37	10.26					
Li_2O	6.78	n.d.	n.d.	.38	.22					
H_2O+	.28	.24	.30	4.72	5.80					.40
TiO_2										47.80
Cb_2O_5							40.37	39.94	none	6.20
Ta_2O_5						2.42	41.14	42.96	79.01	34.80
SnO_2						94.36	.13	tr.	.39	1.30
MnO							9.09	8.82	12.13	
	100.31	99.55	99.72	100.23	100.54	99.58	99.89	100.31	99.86	99.80
Sp. G.	3.167	2.554	2.622	2.855	2.818					

1. Spodumene from a large crystal cut by lower tunnel. Analyst R. J. Leonard.
2. Microcline. Unaltered cleavage fragments. Analyst R. J. Leonard.
3. Albite. Fresh fragments showing curved lamellæ. Analyst R. J. Leonard.
4. Mica. Fine greenish-colored aggregate like lepidolite. Analyst R. J. Leonard.
5. Mica. Coarser light greenish-colored aggregate. Analyst R. J. Leonard.
6. Cassiterite. First mass found in Etta mine. Headden, *Proc. Col. Sci. Soc.*, vol. 8, p. 167 (1916).
7. Columbite. One of a group of crystals weighing 30¼ pounds. Headden, *Am. Jour. Sci.*, vol. 41, p. 95 (1891).
8. Columbite. Crystal weighing 14 pounds. Headden, *Am. Jour. Sci.*, vol. 41, p. 95 (1891).
9. Tantalite. Shaeffer, *Trans. A. I. M. E.*, vol. 13, p. 232 (1884).
10. Struverite. Hess and Wells, *Am. Jour. Sci.*, vol. 31, p. 442 (1911).

Others which may be easily found on the dumps include columbite, tantalite, lepidolite, apatite, beryl, lithiophylite, cassiterite, triphylite, and opal. In addition the following have been mentioned in published articles, or were seen by the writer: struverite, cuprocassiterite, stannite, malachite, purpurite, scorodite, heterosite, tapiolite, amblygonite, biotite, leucopyrite, tourmaline, autunite, triplite. Many others have been found in the pegmatites of the region as noted by Ziegler.[16]

Spodumene.—The occurrence of spodumene has been described in some detail above. Although this is the most important known occurrence of the mineral, no analysis of it from this locality has been published. Ziegler[17] records the determination of lithia of three specimens as 6.16 per cent., 3.56 per cent., and 1.18 per cent. respectively. Mr. R. J. Leonard has made a complete analysis of almost perfectly fresh material obtained from a large crystal cut by the lower tunnel. (See table of analyses.)

Microscopic examination of thin sections and powdered mineral shows the uniformity of the material. The powder shows excellent cleavage fragments, the large ones being somewhat clouded by minute fractures. The maximum extinction angle measured on these fragments is 31° which is somewhat above that given in published tables. (Winchell gives 26° and Larsen 24°.) Considerable dispersion is shown by some fragments and this also is at variance with published data.

The spodumene alters quickly on exposure and develops a fibrous structure. Some crystals have altered to a greenish talc-like mass whereas the fresh material is almost transparent. The writer and Mr. Leonard are preparing a paper describing the alteration in detail and including analyses of a gradational series of specimens.

Mica.—The Etta mine was worked for mica previous to 1883. Large plates of muscovite are common and the "selvage zone" described above is composed dominantly of interlocking muscovite plates up to two inches across. This varies from colorless to a light green. The fine-grained phases of the pegmatite contain

[16] *Op. cit., Min. and Sci. Press,* vol. 108, pp. 604–608, 1914.

[17] Ziegler, V., South Dakota School of Mines Bull. 10, p. 152 (1914).

small light greenish mica flakes. At places are masses of fine mica scales approximately a millimeter across and practically pure. This has a decided green color and was labeled lepidolite as Ziegler states that green lepidolite is found in the Etta mine.[18] More common are aggregates of flakes about 5 mm. across and of a lighter green color. This was labeled lepidolite with a question. Mr. Leonard has analyzed these green specimens and shows conclusively that they are not lepidolite (Analyses Nos. 4 and 5), but muscovite. Under the circumstances there is doubt as to the existence of green lepidolite in the Etta and other pegmatite mines of the region.

Biotite was found in the metamorphosed schist within a few feet of the contact, but was not recognized in the pegmatite.

Feldspar.—The principal feldspar in the pegmatite is microcline, but some albite is found at places and oligoclase has been noted by other investigators. Microcline with milky quartz forms the principal part of the matrix in which the huge spodumene crystals are embedded. An analysis given in the table is of interest in connection with the recent commercial use of the material at Chicago. The content of soda is decidedly lower and the potassium higher than that of most feldspar on the market. A microscopic examination indicates the presence of the soda as albite included in the microcline.

Albite occurs as masses showing the characteristic curved lamellar form. It has a decidedly dark gray cast in large fragments. The powder shows few twinning bands, probably due to its coarseness. The analysis given in the table shows it to be unusually pure, being especially free from calcium and having a relatively low potassium content. Albite was not noted in large amounts either on the dumps or in the mine except in fine aggregates with mica, quartz, apatite and small specks of cassiterite. These aggregates occur as masses in the coarser pegmatitic material exposed in the pit. Fine muscovite scales are found along some of the cleavage faces of the large masses.

Cassiterite.—As previously noted, the occurrence of cassiterite

[18] Ziegler, V., South Dakota School of Mines Bull. 10, p. 177 (1914).

first attracted notice in the Etta mine in 1883. Blake [19] states: "The first masses of tin ores were embedded in the midst of the crystals of spodumene and of feldspar, and yielded fragments of nearly pure cassiterite weighing from one to fifty pounds or more. The chief associate or gangue of the tin ore is, however, a dense aggregation of small crystals of mica, of a light yellow color, forming irregular veins and bunches in the midst of the granitic mass. In this micaceous rock, formed of the mica with a white spar apparently albite, the tin ore is disseminated in grains from the size of a mustard seed to the size of peas, and sometimes an inch in diameter."

Headden has given an analysis of the first large mass found which shows it to be comparatively pure SnO_2. (See table.) At the present time cassiterite is comparatively uncommon and usually is found only as small grains, although other prospects in the region yield good specimens. Mr. James Cessna [20] reported that cassiterite was rather abundant in the upper part of the deposit, but is not found in any amount now.

Columbite-Tantalite.—These minerals commonly occur as isomorphous mixtures and this occurrence is not an exception. Columbite was recognized at an early date by Blake.[21] Later Shaeffer [22] analyzed a sample submitted to him and found it to be nearly pure tantalite. (See analysis No. 9.) Several brief papers on the minerals appeared and Headden [23] reported a very complete study of the two minerals with many analyses. Two typical ones from the Etta mine are given in the table. From descriptions it is apparent that columbite-tantalite like cassiterite was abundant in the upper part of the mine. Columbite (or columbite-tantalite) may be found in considerable masses at the

[19] Blake, W. P., "Cassiterite, Spodumene, and Beryl in the Black Hills, Dakota," *Am. Jour. Sci.*, vol. 26, p. 235 (1883).

[20] Personal communication.

[21] Blake, W. P., "Columbite in the Black Hills of Dakota," *Am. Jour. Sci.*, vol. 28, p. 340 (1884); "Tantalite and Columbite in the Black Hills of Dakota," *Trans. Am. Inst. Min. Eng.*, vol. 13, p. 696 (1885).

[22] Shaeffer, C. A., "Note on Tantalite, etc.," *Trans. Am. Inst. Min. Eng.*, vol. 13, pp. 231–233 (1884).

[23] Headden, W. P., "Columbite and Tantalite," *Am. Jour. Sci.*, vol. 41, pp. 89–102 (1891).

present time. During the war the material was picked out and shipped. The crystals often show what is apparently an oscillatory combination on one side of a tabular crystal.

The other minerals listed are not particularly abundant nor commercially important, and need not be described here. Details on them are available in the references cited in this paper.

CONDITIONS OF FORMATION.

That the deposit which forms the Etta mine is a pegmatite which originated by the offshoots of the more mobile parts of a granite mass is obvious. There are, however, some unusual features of this and other pegmatites in the region which may be noted. The huge crystals of spodumene in the Etta are so large, even for pegmatites, that some abnormal conditions must have prevailed at the time of formation which resulted in what might be termed superpegmatites. The key to the reasons for these unusual deposits is the nature of the Harney Peak granite mass. The pegmatitic nature and lack of a normal granite phase has been emphasized. In fact it would not be far from correct to refer to all the exposed Harney Peak granite as a pegmatite. The writer believes that this granite was possessed of an unusually high content of volatile constituents and that the parts rejected by crystallization of the main mass at depth were of great quantity and extremely mobile. The great series of pegmatites, some several miles from exposed granite, seem proof of this. Before considering the direct cause of the formation of the huge spodumene crystals, it should be emphasized that other minerals of the deposit show very large crystals and masses but less perfect and striking than in the case of spodumene. Columbite forms large crystals in the Etta and occurred as masses of 600 pounds.[24] Cassiterite was also found as large masses in the upper part of the deposit. At the Hugo mine, 1,000 feet west of the Etta, are masses consisting of many tons of feldspar which appear remarkably pure. Crystals of tourmaline several inches across are also found there. Masses of very pure amblygonite, lepidolite, and beryl, aggregating tons, are found in the Bob Inger-

[24] Hess, F. L., U. S. Geol. Survey Bull. 380, pp. 131–161, 1909.

soll mine. Other examples might be cited. This segregation of the minerals, even within a single deposit, into large masses indicates not only extreme mobility, but a sort of mass action on a tremendous scale so that crystallization once started continued until all the material of the proper composition for a considerable radius was concentrated into one mass. In the case of spodumene this meant into crystals, commonly ranging from ten to forty feet in length.

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MODE OF FORMATION OF THE PORCUPINE QUARTZ VEINS.

ELLSWORTH Y. DOUGHERTY.

INTRODUCTION.

THE most ambitious recent attempt to explain the mode of formation of gold-quartz veins is by Spurr in his Ore Magmas and auxiliary writings. Spurr sees in the so-called "pegmatitic" (coarse-grained) quartz veins, strong analogies with igneous dikes and reasons that the mode of formation is similar for both. He contends that the quartz "vein-dikes" have been formed by forcible injection, the injected "ore magma" distending the walls of the invaded fissure. Some other geologists believe that quartz veins have grown by the force of crystallization; that the growing crystals themselves, rather than the vein fluids, have exerted pressure on the walls of fissures and have forced these walls apart. Others maintain that the major process is simply open fissure filling. Still others imagine a growth of the veins "by permission," that is the opening of fissures by external stress, and as they widen, the simultaneous filling of these fissures by vein substance. Another group believe the process is mainly a chemical one; that the quartzose fluids have dissolved the invaded rock along the walls of fissures and have solidified in the spaces thus produced.

The Porcupine district of Ontario, Canada, is a fertile field for study of gold-quartz vein phenomena. Within the mines are numerous clear exposures of quartz veins and lodes of extraordinary diversity and complexity, cutting rocks of strongly developed physical characteristics, thus affording unusual opportunity for fruitful structural studies of the lodes and rocks.

As a basis for discussion I have selected the more instructive examples from a series of sketches and photographs made by me

during the years 1916 and 1917 (Figs. 1 to 5), and one recently published by Robinson [1] (Fig. 6).

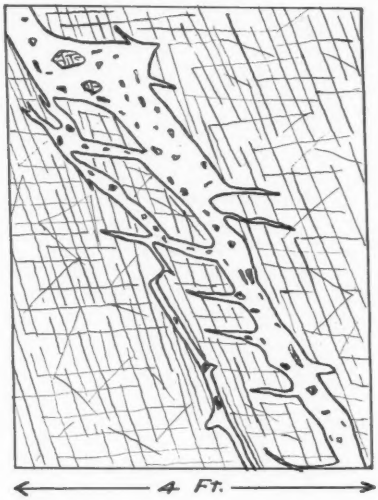

FIG. 1. Vertical section of quartz veins in jointed greenstone. 1,000 ft. level, McIntyre Mine. Lines represent joints. Numerous inclusions within the veins are same materials as wall-rock.

OPEN FISSURE FILLING.

The wall rock inclusions, pictured in the figures, show that none of the veins in which they are found were formed in fissures that stood open from margin to margin. It is immaterial whether or not the inclusions are completely isolated by vein substance, the mere fact of their presence within the vein demonstrates that the entire width of vein was not formed in an open fissure, since rock substance occupied part of the space. None of the veins shown in the figures, measurable in feet, and few measurable in inches are without visible inclusions and many more are revealed by magnification. It is therefore certain that

[1] "Geology of the Pearl Lake Area, Porcupine District, Ontario," by H. S. Robinson, ECON. GEOL., vol. XVIII., No. 8, Dec., 1923.

the filling of fissures open from wall to wall of the veins, cannot explain the Porcupine veins.

Another view might postulate that vein substance filled spaces between the inclusions and fissure walls. This condition may be visualized by imagining the removal of vein substance in the figures. When this is done many inclusions hang without support and it is therefore impossible to maintain that there was open space around them when vein-forming solutions entered. A view of the inclusions in a single plane cannot prove their complete isolation, but examination of hand specimens leaves no doubt that many are completely surrounded by vein substance.

There are many other considerations that argue against the assumption of an origin by open fissure filling alone, but it will suffice here to point out the nature of the fissures along which the veins were formed. The joints of Fig. 1, fissility of Fig. 2,

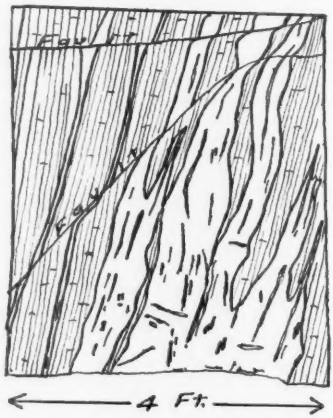

FIG. 2. Vertical section of quartz veins in fissile chlorite schist. 300 ft. level, McIntyre-Jupiter Mine. Lines represent the fissility. Bands and patches within veins are wall-rock inclusions.

schistosity of Fig. 3, and shearing of Fig. 4, indicate the fissuring of the rocks along numerous surfaces of differential movement, through the agency of compressive earth stress. These

fissures are now tight or very narrow in their present near-surface environment and it is difficult to believe that they gaped open for the width of the introduced vein substance, in far greater depth.

FIG. 3. Vertical section of quartz veins in contorted sericite schist (altered Pearl Lake quartz porphyry). 1,000 ft. level, McIntyre Mine. Lines represent the schistosity. Bands and patches within veins are wall-rock inclusions.

Yet the obvious control on the disposition of the veins, by the joints, fissility, schistosity and shearing shown in the figures, shows that the veins followed fissures and therefore that fissure filling played a part. The only difference of opinion that can validly exist, is in the relative importance of fissure filling and other modes of formation. Detailed study leads to the conclusion that there has been filling of numerous narrow partings, such as the joints, fissility, schistosity and sheared surfaces of Figs. 1 to 4 but that the present volumes of vein material must have been developed in large part by modification of the vein fis-

sures during the mechanism of vein formation. If this is true, it is necessary to infer that the vein fissures were obligingly opened to receive vein forming solutions, or that the vein substance provided part of the space for itself.

MECHANICAL OPENING OF FISSURES.

If vein fluids have entered a series of narrow partings similar to those now visible near some of the veins (Figs. 1 to 4), or those that may be inferred from the structure of the lodes (Figs. 5 and 6), the mechanical opening of fissures must explain the partial elimination of intervening walls of these partings. Numerous inclusions in Figs. 1 to 4 show that the larger veins were not formed by vein substance entering along single openings, but if along a series of openings, what has happened to the intervening walls? Are the inclusions the remnants of country rock, squeezed so strongly that it has flowed upward or downward or transverse to the sections? Apart from lack of evidence of this squeezing, such flow of the rocks would be impossible, because there would be no escape in the complex system of fissures that frequently surround the inclusions when considered in three dimensions. If continuous or nearly continuous fissile or sheeted bands of rock, suggested by Figs. 2 and 4, once passed through the places now occupied by quartz, the mechanical opening of fissures cannot explain their partial disappearance and chemical dissolution, and therefore elimination of the rock, is a necessary conclusion.

Strong as the inference is, however, it cannot be absolutely proved that country rock has occupied space in the veins where now no rock exists. There would be clear proof if vein quartz reproduced the structure and texture of the country rock, but such conditions are not present. Replacement, if a fact, was not of a type that preserves faithfully the fabric of the replaced substance. In view of this, a test of the validity of the mechanical opening of fissures should be made without recourse to the assumption that the fissures can be visualized before ore deposition.

A starting point can be established upon the indisputable prem-

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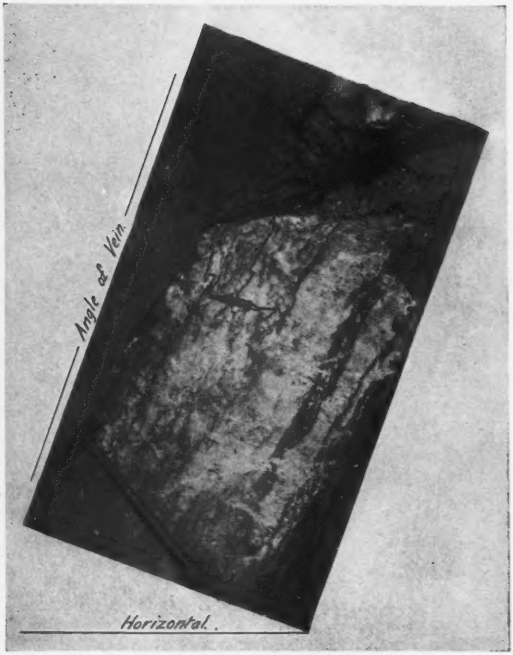

FIG. 4. Photograph in vertical plane of quartz vein in black sheared schist. 600 ft. level McIntyre Mine. Note the numerous bands of country rock paralleling the vein margins.

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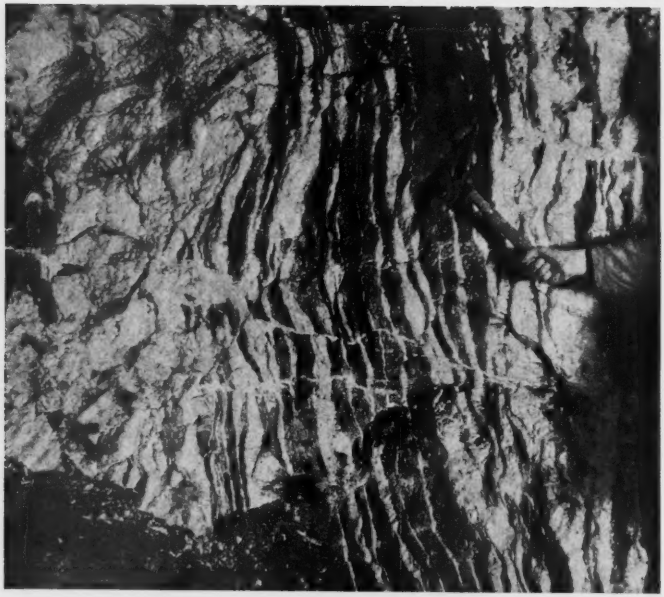
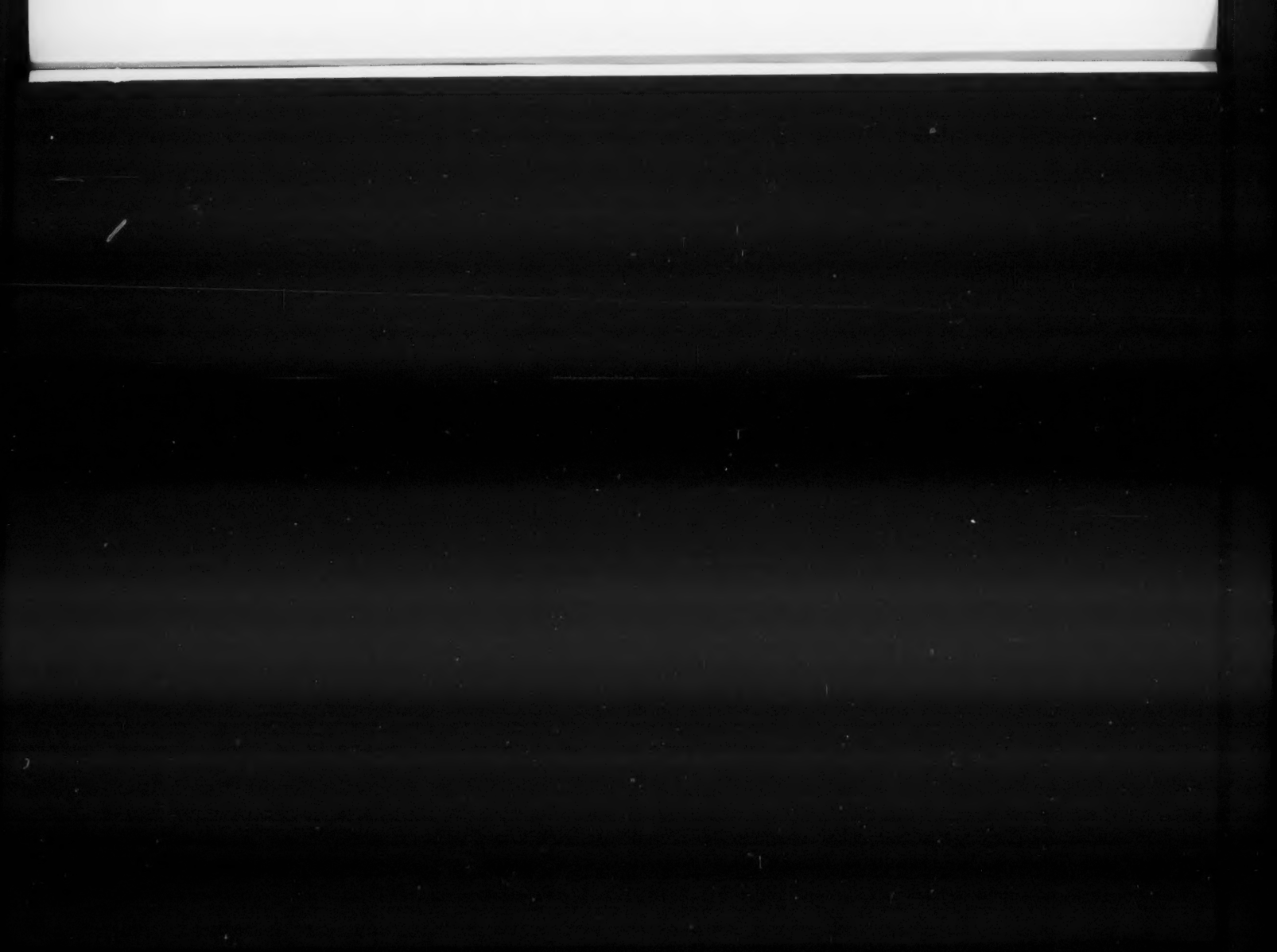


FIG. 6. Banded quartz lode No. 7 vein McIntyre Mine. After H. S. Robinson.



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ise that unsupported inclusions must be brought in contact with the solid country rock, to produce possible conditions at the inauguration of vein fluid entrance. This can be done:

(1) By allowing either the wall rock or inclusions, or both, to expand, until sufficient points of contact are made to insure the support of the inclusions.

(2) By allowing the unsupported inclusions to "float" over against some supporting contact with solid wall rock, without change in volume, thereby making no change in volume of openings as now represented by vein substance.

(3) After (2) is accomplished, by allowing the solid wall rock to close in bodily or by expansion, so as to close openings to any degree desired.

(4) By allowing the solid wall rock to close in bodily, that is without change in volume, on the inclusions, to insure their support, while the inclusions remain stationary.

(5) By combinations of the above.

Briefly, there must be dilatation or dislocation, or both. In order to give support to the inclusions, there must be expansion of the rock area in the plane of the sections, either of the inclusions or wall rock, or both; or there must be movement together of inclusions and wall rock without change of volume, or some combination of expansion and movement. Conversely, during vein formation, there must have been reduction in rock area, in the plane of the sections; or a prying apart of inclusions from the wall rock, or both.

Now, if there has been the tremendous reduction in volume necessitated by dilatation, this assuredly should be expressed by deformation of the rock. This squeezing should be especially apparent on comparatively massive inclusions such as those of Fig. 1, whereas it is not. Or if, as supposed by Spurr [2] in the example of the pegmatite injection pictured and described as an example of forcible distension of fissure walls, the inclusions have remained rigid because of counter-balancing forces, then the deformation that forced the wall rock away from the inclusions

[2] "The Ore Magmas," page 577.

must have been taken up between veins. In examples of massive wall rocks such as that pictured in Figs. 1 and 5, there should be especially plain evidence of deformation along the veins. There is no such evidence either of contraction or dislocation. The veins are simply frozen against undisturbed wall rock, essentially

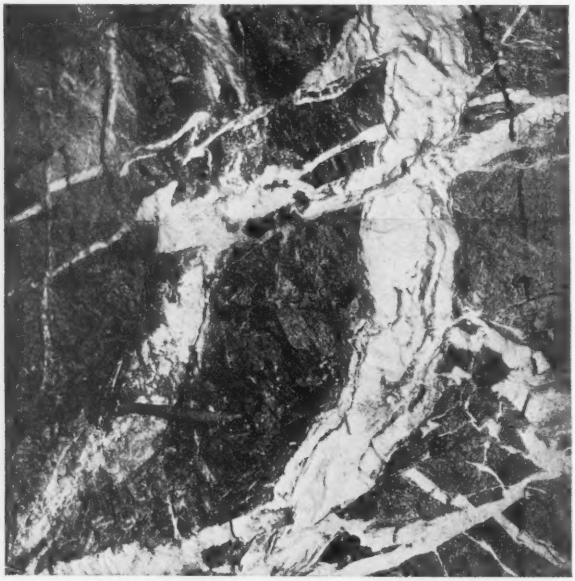

FIG. 5. Photograph in vertical plane of quartz veins in massive greenstone. 400* ft. level, Newray Mine. Note wall-rock bands paralleling vein margins.

the same as the rock at a distance from them. As one views the characteristic undisturbed edges of pliable schist in contact with the veins, in Figs. 2 and 3, it is difficult to entertain belief that overpowering mechanical pressure, outward from the veins, acted upon the walls of the veins.

When the section shown in Fig. 3 was exposed, a superficial view suggested that here was plain evidence of the distorting

effect of growing quartz veins. As pictured, the pliable schist is bent at the contact with the larger vein, in the right-center portion of the sketch. Close observation shows, however, that this is merely a local condition, for there are numerous places where there is no bending of the schist at its contact with the veins. A simple explanation satisfactorily explains the relations; as follows: The distortion of the schist was accompanied or followed by fissuring, some fissures cross-cutting at bends in the schistosity. The vein substance followed these fissures and therefore now cuts across the schist where it was bent and ruptured.

Nor does this study disclose any supporting evidence for the hypothesis that the inclusions have moved away from their walls. Their whole aspect is that of rock bodies occupying exactly the same position as before vein formation. If the inclusions of Figs. 1 to 4 have "floated free," or have been dislocated, it is a remarkable coincidence that the jointing, fissility, schistosity and sheeting have so consistently remained parallel to similar structures of the wall rock; also that isolated bands within the veins characteristically parallel the walls of veins, or banding outside the veins in solid wall rock (Figs. 4, 5, and 6).

REPLACEMENT.

The nature of the abundant isolated inclusions in the veins is a strong argument for large scale replacement. Spurr mentions [3] to support his conclusion of the "intrusive" origin of the Porcupine "veindikes," and therefore presumably the supporting power of the intruding solutions, the inclusion of unsupported fragments of wall rock in the veins. This is shown in Fig. 2 of Spurr's article, which pictures an example of so-called "angular" inclusions. Note the rounded outline of some of the inclusions, and the frequent uneven and indented rock-vein contacts. Note also the penetration of the inclusions by white vein material. Surely these inclusions have all the appearance of having been attacked by vein substance. In view of this, unless there is evidence that the inclusions have been rotated, it is a justifiable in-

[3] *Engineering and Mining Journal-Press*, Oct. 13, 1923.

ference that replacement, rather than displacement effected their isolation.

A study of the vein-inclusion contacts of Fig. 6 shows the uneven frayed edges of many of the inclusions. The attack and penetration of the inclusions are apparent. No evidence of their disturbance is apparent from the photograph. On the contrary it is significant that many unsupported bands parallel bands of wall rock shown in the central portion of the photograph. The whole aspect of the inclusions is that of unreplaced remnants, not of disturbed fragments pressed or floated away from their supporting walls.

Sharp smooth walls of veins and straight sharp contacts along portions of the vein-rock contacts are not infrequent. But this is no conclusive argument against replacement with ore bodies formed along fissures. In all the sections the control of fissures is evident and it is not necessary or logical to assume that the linear configuration of their margins would always be modified. In the invasion of numerous closely spaced fissures many fissure walls may escape attack. Vein fluids may invade the more open portion of the rock on one side of a fissure wall, replacing the rock up to and against the wall and leaving the less penetrable rock on the other side of the wall untouched. The result would be a vein with one or more sharp walls. Such a condition is common at Porcupine. As would be expected where fissure filling and replacement were both operating, some vein-rock contacts are sharp while others are vague. Some inclusions are angular but many have rounded, sinuous outlines. It is not necessary to assume, however, that angular inclusions, or inclusions with partly straight edges, prove the absence of replacement. Bateman has recently shown [4] that angularity of rock inclusions in veins is an unreliable argument against replacement.

Replacement satisfactorily explains many of the irregularities of the veins and their modification of and deviation from the structure of the country rock. Isolated irregular masses of

[4] Bateman, A. M., "Angular Inclusions and Replacement Deposits," ECONOMIC GEOLOGY, vol. XIX., No. 6, Sept.–Oct., 1924

quartz, as in Fig. 3, with grotesque forms, are satisfactorily catalogued as fillings with modification of the invaded fissure walls by replacement. Fig. 1 suggests that though the veins have followed joints, there has been considerable modification of this control. The edges of the veins may be undulating, whereas the jointing is comparatively straight. Intersections of the veins are partly along curved paths, whereas the joints in the country rock meet along straight lines. In Fig. 2 the sinuosity of some of the veins is not paralleled by a conformable contortion of the schist. Undulating margins of the veins mainly cut across the fissility. In the absence of evidence of mechanical disturbance, the conditions shown in Figs. 1 and 2 suggest that vein forming solutions have modified the country rock structure by chemical dissolution.

CONCLUSIONS.

This study leads to the conclusion that the Porcupine quartz veins have been formed by the insinuating penetration of numerous tight or very narrow fissures, and replacement of the contiguous rock. No evidence can be found to support the hypothesis of forcible disruption of fissure walls as Spurr has assumed for veindikes. I agree with Spurr that the veins were probably formed from fluids injected into the wall rocks. The veins cut all the rocks of pre-ore age regardless of chemical constitution and manifestly follow the more penetrable portions of the rocks. In these respects and in their form and structure, they have all the attributes of intrusive mineral bodies. But it does not at all follow that the injection was accompanied by forcible disruption of the walls of fissures. Plausible as this notion is, as far as this study discloses it lacks corroborative evidence. More tenable is the view that vein fluids have assiduously sought the more penetrable portions of the rocks, exerting hydrostatic and vapor pressure against frictional resistance, rock pressure and gravity, expending force in penetration and chemical dissolution, rather than in disruption of the invaded rock.

At the temperature of vein formation heat alone could not

have fluidized the silica, therefore it must have been in solution. The dissolving fluids have parted company from silica. If replacement accounts for the emplacement of huge masses of quartz found at Porcupine, a tremendous quantity of rock has been removed to make way for this quartz. It is obvious that crystallized quartz could not have carried away the removed rock and remain behind itself. It is to the efficacy of the fluids that held silica in solution that removal of the country rock may logically be ascribed. It follows that we are not justified in assuming that the vein-forming solutions had anything like a concentration of silica that might be inferred from imagining vein quartz injected in the fluid state.

HEROULT, CALIF.

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THE BAUXITE DEPOSITS OF SOUTHEASTERN ALABAMA.

R. E. RETTGER.

THE presence of bauxite in southeastern Alabama has been known for several years but only recently have the deposits been extensively explored and prospected. The bauxite occurs in an area some twenty miles long and ten miles wide in Barbour and Henry Counties, Alabama, the locus of the deposits being about thirteen miles southwest of Eufaula.

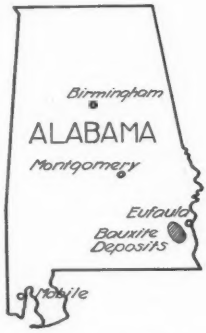

FIG. 1. Outline map of Alabama showing the location of the bauxite deposits described in this paper.

Up to the present time no bauxite has been mined from this area owing to the recent date of its development and unfortunate location in regard to railroad facilities, the deposits being 13 miles from the nearest loading point.

The writer has recently done considerable detailed work in the district and has had an opportunity to study the various deposits. During the prospecting, which covered a period of about twelve months, some 200 different "shows" were tested on more than

60 properties. From these 200 "shows," 75 deposits were outlined containing a fair amount of merchantable ore. The prospecting consisted of test-pitting and drilling, and in all more than 2,000 bore holes were put down supplemented by many test pits. About 1,000 partial analyses (SiO_2, Fe_2O_3, Al_2O_3, TiO_2, and loss on ignition) were made of bauxite and associated clay.

GENERAL GEOLOGY.

The Coastal Plain of Alabama and Georgia is composed of Cretaceous and later formations which dip gently (25′–40′ per mile) to the south, and, in the area under consideration, strike approximately east and west. The formations for the most part are unconsolidated sands, clays, and marls with occasional indurated limestone beds.

According to E. A. Smith,[1] the coastal-plain formations, beginning with the top of the Cretaceous up through the Eocene, are as follows:

Upper Cretaceous.

Ripley.—The Ripley formation or Ripley marl underlies the entire area and comprises about 1,000 feet of black and gray marl with occasional indurated limey beds so that it is easily recognized in outcrop.

Tertiary.

Eocene.—The formations of Eocene Age directly overlie the Ripley, and occupy that portion of Alabama and Georgia south of the area occupied by the Ripley. They have been subdivided into the following divisions:

Midway.—In the eastern part of Alabama, the Midway is represented only by the Clayton Limestone, which along the Chattahoochee River reaches a thickness of about 250 feet. This formation lies unconformably over the Ripley and is composed largely of calcareous sand and loose sand, there being only a lower and upper limestone member with occasional limestone beds between.

[1] Smith, E. A., Geol. map of Ala., Geol. Surv. of Ala., 1894.

Wilcox.—Unconformably overlying the Clayton Limestone is the Wilcox which has been subdivided into the Nanafalia, Tuscahoma, Bashi, and Hatchetigbee, the first being the oldest and lowermost. The Nanafalia is composed of about 150 feet of massive and laminated sands and clays, cross-bedded sands, highly fossiliferous greensand, marl, and thick-bedded clays. The Tuscahoma consists of 150 to 200 feet of sands, sandy clays, laminated clays and greensands. Above the Tuscahoma are the Bashi and Hatchetigbee followed by the Claiborne and Jackson groups, all of which outcrop successively farther to the south.

THE BAUXITE DEPOSITS.

Geologic Relationships.—The bauxite deposits in this area occur in association with the Clayton Limestone, the only member of the Midway present in Eastern Alabama. They apparently occur on the irregular surface of this formation, and at its contact with the overlying Nanafalia (Wilcox). It is probable that a large part of the present outcropping Clayton was never covered by later sediments, the Nanafalia (Wilcox) sea probably never having gone much farther north than the present position of that formation.[2] The present outcrop of the Clayton, then, thins to the north due to original deposition and to some erosion. This surface, therefore, is in part practically the same as that upon which the overlying Wilcox was deposited. The bauxite deposits are thus not confined to any particular horizon within the Clayton, their position being controlled largely by the unconformity and the old Clayton surface.

In this area the Clayton limestone formation is by no means all limestone, it being composed of loose, silicious sands, partially cemented calcareous sands, clays and limestone. In general, however, it is considerably more limey than the underlying and overlying formations, being known for its many lime springs. During drilling operations, at no place was limestone encountered with the drill. Either it was never present close to the bauxite or else it has been leached away.

[2] Berry, E. W., "Erosion Intervals in the Eocene of the Mississippi Embayment," Prof. Paper 95–F, U. S. G. S., 1915.

In practically every case the bauxite was found grading downward and laterally into an associated clay. No case was noticed during the entire drilling where the clay graded downward into bauxite. Moreover, the deposits show no bedding nor other dis-

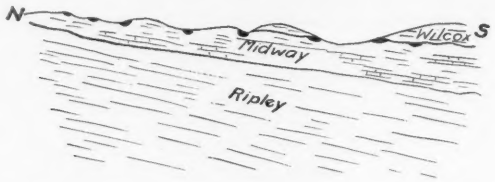

FIG. 2. Idealized cross-section through the bauxite area showing the possible relation of the deposits to the surface of the Midway and the unconformity between the Midway and the Wilcox. (The heavy black indicates the bauxite deposits.)

tinct sedimentary structures. Lignitic clay is found at several places closely associated with the bauxite and clay. The ore, for the most part, is alum grade although there is some metal and abrasive material present.

Character of Deposits.—The shapes of the deposits are quite varied, but on the whole are different from those of Central Georgia which, although similar in many other respects, are lens shaped. Here they are undoubtedly not beds nor lenses, but pockets whose vertical dimension is sometimes as large as the horizontal.

The deposits are in general, small. The largest is some 200 feet long and 100 feet wide, but most of them are considerably smaller.

The thickness of the deposits varies from one foot to more than fifty, the average maximum thickness being about fifteen feet.

Here, as in other localities, the bauxite is closely associated with bauxitic clay and clay, there being a complete gradation among the three.

The ore shows the following types: (1) red oölitic, hard; (2) red amorphous, hard; (3) white oölitic, hard or soft; (4) white

amorphous, hard or soft, and (5) white amorphous, soft and semi-plastic.

Where red ore is present in a deposit, it is generally near the top and grades downward into pink or white material. The hard ores, in most cases, because of their resistance to erosion, occur

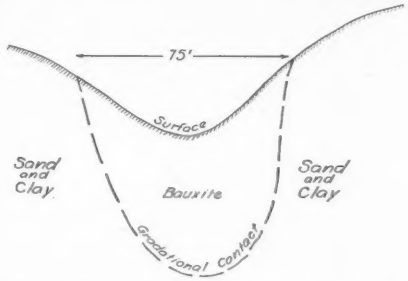

FIG. 3. Cross-section of a deposit in southeastern Alabama showing the "pocket" shape of the bauxite. This particular deposit occurs in a stream valley which fact accounts for the surface depression.

as cappings on small hills, whereas the soft ores show no topographic variations. The red color of the ore is due to the presence of iron oxide presumably in the form of limonite which is, in many cases, distinctly secondary. That the red color is secondary is clearly shown by its relation both to the surface and to fissures or cracks in the bauxite. Quite often the staining follows fissures, evidently having seeped into the bauxite from along the crack.

ORIGIN OF THE BAUXITE.

Formation of the Clay.—It is supposed that in pre-Cretaceous times the crystalline rocks of the Piedmont area to the north were long exposed to weathering which decomposed and disintegrated them to a great extent, forming thick blankets of residual clay and sand. During Cretaceous and later time, owing to rejuvenation, streams began to carry this material southward and to deposit it either in shallow depressions such as lakes or lagoons near the coast, or in the shallow waters off the coast. This material,

having been long subjected to weathering conditions, contained a large amount of clay which, during transportation, was separated from the coarser sand and, where conditions were favorable, was deposited in a remarkably pure state. Presumably, the "favorable conditions" were periods of slow water movement. There would thus be formed clay lenses of varying size, surrounded and covered with sands deposited under more rapid water conditions. It is in this way, the writer believes, that many of the large clay deposits of the Coastal Plain were formed. The bauxite deposits represent an alteration of these clay lenses.

Formation of the Bauxite.—After the deposition of the clay in the lagoons, lakes, and shallow coastal waters, during Clayton time, there was a period during which no material was brought from the north. At this time the land was perhaps slightly elevated so that it existed as a fairly low, flat plain. Erosion was not severe, but weathering (decomposition) proceeded at a normal rate. The clay deposits near the top of the Clayton formation were, therefore, exposed to the action of solutions without being subject to immediate removal by erosion. Undoubtedly the temperature was extremely mild. Under these conditions the clay was altered to bauxitic clay and bauxite by the removal of silica and the addition of water. The altering solutions are supposed to have been those ordinarily present at the surface such as carbonic acid or humic acid. Sulphuric acid may have been an important reagent although the evidence for its presence is not clear. Nitric acid may also have played a part.

The points in favor of this theory for the southeastern Alabama deposits may be summarized as follows:

1. The deposits are associated with an erosional surface. (They were probably formed during the interval between the Clayton (Midway) and the overlying Nanafalia (Wilcox) since pebbles of bauxite are found in the overlying formation.)

2. There is a gradation from bauxite to bauxitic clay to clay. The bauxite, however, usually overlies the clay, except in places where it is unconformably covered by later sediments. (There may be local exceptions to this.)

3. There are no sedimentary structures in the bauxite which indicate that it was deposited in its present form. If oölitic or pisolitic material had been deposited as such, one would reasonably expect to find the oölites and pisolites arranged in layers or beds (even on hand specimen scale).

4. There is no evident source for hot water in this vicinity; neither is there alteration in any of the sediments which would indicate thermal solutions.

There are several characteristics of the deposits, however, which do not at first glance accord with the writer's hypothesis.

The bauxite does not show in all cases a porous texture such as one might expect after the leaching out of the silica from the clay. Theoretically this should produce a pore space of about 18 per cent.[3] allowing for no slump. In the harder phases of the bauxite, however, the porous texture is sometimes evident. It is thought that, in most cases, the pore space has been taken up by slump or by enrichment or by both.

Practically all of the clay, bauxitic clay, and bauxite contains some titanium dioxide. The percentage content, however, is not related to the alumina content, some of the clays being high in TiO_2 and some low. This is true also of bauxitic clay and bauxite. Many analyses have been examined and in all cases the alumina and TiO_2 bear no definite relation to one another. In other words, the TiO_2 has not been concentrated along with the alumina.[4] The TiO_2 is probably present as either rutile or ilmenite, more likely the former, and is extremely finely divided. Veach[5] examined microscopically some clays whose analyses showed TiO_2 but was unable to determine any titanium minerals. Somers,[6] however, has identified rutile in practically all clays ex-

[3] Leith and Mead, "Metamorphic Geology," New York, 1915, p. 31.

[4] Quoting from Clarke's "Data of Geochemistry," "The titanium, for example, which was first observed in bauxite by H. Sainte-Claire Deville, is such a product of concentration, and is found not only in bauxite but in nearly all residual clays." The writer would question the word "concentration."

[5] Veach, Otto, "Clay Deposits of Georgia," Georgia Geol. Surv. Bull. 18, p. 48, 1909.

[6] Somers, R. E., "Tables in High Grade Clay of Eastern United States," Bull. 708, U. S. G. S., p. 292, 1922.

amined by him. In discussing the bauxite of Georgia, Shearer [7] says that " The bauxite consists essentially of a mixture of gibbsite and kaolin and contains iron and titanium in about the same proportion as the associated kaolin. Percentages of soda, potash, lime, and magnesia are lower in the bauxite than in the kaolin."

From the above it is evident that the titanium-bearing mineral either has about the same solubility as the silica of the kaolin or is secondary as is probably some of the iron, otherwise it means that the alumina per cent. has been increased both by leaching of silica and by secondary enrichment. Since the titanium does not vary with the iron content, one is inclined to favor the first or the third alternative.

The deposits in southeastern Alabama are like those of northwestern Georgia in that they occur in pockets whose vertical dimension is sometimes as large as the horizontal. According to Watson [8] this shape of bauxite deposit could not possibly have resulted from any known process of weathering. Hayes [9] also, in his report of the northwestern Georgia deposits, seems to have had this in mind. To the writer, this is not a serious objection as one would naturally expect alteration to extend downward at least to the water-table at places where circulation was perhaps a little freer than at others. Water channels once opened would allow free movement of water and would localize alteration in their vicinity. This localization could easily produce a shallow pocket deposit. In this connection the leaching of the Lake Superior iron ores should be remembered. It is evident there that silica has been removed by surface waters to great depths.

Finally it is seen that these deposits are more or less unique in that they are pocket deposits in Coastal Plain sediments, no similar ones having been described before. They are, however, quite like the deposits of central Georgia in general characteristics and

[7] Shearer, H. K., " Bauxite and Fullers' Earth Deposits of the Coastal Plain of Georgia," Bull. 31, p. 124, 1917.

[8] Watson, T. L., " A Preliminary Report on the Bauxite Deposits of Georgia," Bull. 11, Geol. Surv. of Georgia, 1904.

[9] U. S. G. S., 16 Ann. Report, III., p. 574, 1895.

are presumably the same age as those in Sumter and Macon Counties, Georgia.[10] The writer, having seen several of these deposits as well as those in Wilkinson County, suggests the possibility that they too may be the result of surface alteration of clay lenses.

Shearer discusses the origin of these Georgia deposits and supposes them to be formed by the action of hydrogen sulphide introduced into lagoons into which kaolin was being deposited. He supposes the hydrogen sulphide to have been derived from finely divided pyrite in the underlying sediments, then carried upward by water which issued as springs (possibly thermal) into lagoons, etc. The hydrogen sulphide was converted into sulphuric acid by the action of the oxygen in the lagoon water which in turn decomposed the kaolin to aluminum sulphate. This aluminum sulphate was carried to a position near the vent of the spring where hydrogen sulphide was present and where the water was neutral or alkaline. Here the aluminum sulphate was hydrolyzed and precipitated as aluminum hydrate. After a certain length of time, the spring is supposed to have ceased or shifted its outlet. This, according to Shearer, would produce bauxite lenses surrounded by kaolin.

Shearer also states the following points which must be explained by a satisfactory theory:

1. The deposits are horizontal, lens-like bodies, seldom if ever more than 10 feet thick and a few acres in extent.

2. The lenses are invariably underlain by sedimentary kaolin. The upper surface of the bauxite is frequently an unconformity, but in some known deposits, and probably originally in all, the bauxite is or was entirely surrounded by kaolin, having the form of a small lens of bauxite within a much larger lens of kaolin.

3. The bauxite was completely formed and indurated to almost its present condition before the end of Cretaceous time, as boulders and pebbles are in the basal conglomerate of the overlying earliest Eocene beds.

4. There is no limestone or any calcareous material either in or under the bauxite-bearing beds, which could have served as a reagent in precipitating the alumina.

[10] Shearer, H. K., *op. cit.*

5. The bauxite consists essentially of a mixture of gibbsite and kaolin, and contains iron and titanium in about the same proportion as the associated kaolin. Percentages of soda, potash, lime and magnesia are lower in the bauxite than in the kaolin.

6. Nodular structure is always present in the ores, in fact, it is developed in some kaolins which contain only a minute amount of aluminum hydrate.

7. The nature of the solutions present during the formation of the bauxite was such that they were able, locally, to deposit pyrite, and to form geodes containing marcasite, sulphur, melanterite, coquimbite, alunogen, and sulphuric acid.

The writer agrees with Shearer that these seven points must be explained by a satisfactory theory of origin but believes they point toward a conclusion different from the one drawn by him.

The first point may be a little misleading when Shearer speaks of "lens-like bodies." This term carries with it the idea of depositional lenses which are the direct result of sedimentation. They should, therefore, being composed of nodules (oölites and pisolites), show a bedded structure. However, they do not; neither is it evident that they always lens out on the edges as would be expected. They are often abrupt and somewhat pockety. This first point then is not opposed to the author's views.

The second point stated by Shearer is that the upper surface of the bauxite is frequently an unconformity and that the bauxite grades downward into kaolin. He states that, in some known deposits and probably originally in all, the bauxite is or was entirely surrounded by kaolin. The fact that the upper surface of the bauxite is usually an unconformity can be observed but that it was originally entirely surrounded by kaolin is a supposition and is doubted by the writer. The close association of the bauxite with an unconformity can not be overlooked, yet, in Shearer's theory, an unconformity plays no part. This second point shows the relation of the bauxite to surface conditions and not necessarily to issuing springs.

The third point has no direct bearing upon the question of origin except that it shows the bauxite to have been formed previous to Eocene deposition.

The fourth point regarding the calcareous material which could precipitate the alumina is really more unfavorable to the theory proposed by Shearer than it is a point in its favor. The absence of such material would not affect the formation of bauxite by surface alteration.

The fifth point regarding the percentages of soda, potash, lime and magnesia, so far as the writer can see, is distinctly in favor of the origin by surface agencies. In any weathering process it is these oxides which show a distinct uniform loss. Possible hydrothermal alteration, on the other hand, as proposed by Shearer, would presumably have brought different results. Such an alteration would increase the potash content, while decreasing that of soda, lime and magnesia, and there should be a development of distinctive minerals such as characterize deposits known to have been affected by hot water. In all the alteration products near extinct volcanoes and present hot springs, there is no known bauxite. Such deposits are characterized by "quartz, iron oxide, calcite, barite, fluorite, kaolin, nontronite, jarosite, alunite, gypsum, and other sulphates, exceptionally adularia and zeolites, all presumably formed under the influence of the carbonic, sulphuric, and other acids contained in the volcanic solutions, both aqueous and gaseous."[11] This point, then, actually favors the theory of formation by surface agencies.

The sixth point, so far as the writer can see, would not materially affect either hypothesis.

The last point made by Shearer is that the solutions present during the formation of the bauxite were such that they were able, locally, to deposit pyrite, and to form geodes containing marcasite, sulphur, melanterite, coquimbite, alunogen and sulphuric acid. From Shearer's report it seems that such solutions were quite localized; in fact, in general the evidence for them is lacking. Moreover, Shearer himself states that these minerals are later than the bauxite but that he believes that they are just a little later. The writer believes from observations and from Shearer's descriptions that they are quite secondary and have no

[11] Leith and Mead, "Metamorphic Geology," New York, 1915, p. 45.

definite bearing on the nature of the solutions present during the formation of the bauxite.

Further, from the writer's observations, the lower limit of the bauxite in these various deposits is quite irregular, suggesting that characteristic pitted feature almost always associated with surface weathering and well illustrated by Mead in his description of the Arkansas deposits.

It is also true that the bauxite of both northwestern Georgia and southeastern Alabama is associated with lignite or lignitic clay, and, as pointed out by Adams,[12] this is not in accord with the theory of hot water deposition.

Finally, from a critical point of view, it would seem that the deposits in central and southern Georgia and southeastern Alabama could be explained by the theory of simple surface alteration by atmospheric agencies. Such an explanation, as pointed out by Adams in discussing the northwestern Georgia deposits, "will do away with the necessity of appealing to the action of hot springs and geysers and likewise permit of a simple explanation of the form and origin of the deposits."

Comparison With Other Deposits.—That bauxite is usually the result of surface alteration and, therefore, associated with an erosion plane or unconformity is apparent from a study of the literature, a review of which may not be out of place here.

In Arkansas, according to Mead,[13] the bauxite deposits were formed by the laterization of a nepheline syenite, the syenite first altering to a kaolinized syenite, then to a kaolin, which on further action of the surface waters in turn loses silica and changes to bauxite. These deposits characteristically show a gradation from syenite outward through kaolin to bauxite, which gradation is controlled by surface waters.

In northwestern Georgia and northeastern Alabama the bauxite occurs in deep pockets in the residual material from the Knox Dolomite. According to Hayes, the deposits are associated with

[12] Adams, G. I., "The Formation of Bauxite in Sink-holes," ECON. GEOL., vol. 18, p. 410, 1923.

[13] Mead, W. J., "Occurrence and Origin of the Bauxite Deposits of Arkansas," ECON. GEOL., vol. 10, p. 28.

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faults and are the result of hot springs issuing into basins and lakes. The alumina was dissolved as the sulphate from the underlying Conasauga shale and brought to the surface by the spring water and deposited as the hydroxide. The soft aluminous gel was presumably kept in motion by the spring water which fact accounts for the oölitic structure.

According to Adams,[14] these deposits represent alterations of clay which has been deposited in sink-holes. He supposes sink-holes to have developed in the Knox Dolomite and later to have been filled with clay. Then, by natural weathering processes, the clay is leached of its silica and converted into bauxite.

The central and southern Georgia deposits have already been referred to on a previous page.

In Mississippi, according to Morse,[15] the bauxite deposits occur in the Ackerman formation (basal Wilcox) near its contact with the Porters Creek Clay (Midway). Very little geologic work, however, has been done here and detailed information showing the relation of the bauxite to an erosion plane is not available.

Turning to foreign countries, we find in general similar structural relations. In southern France, the deposits near Baux and in Var may prove to be the exception in that they are supposedly stratified beds deposited on an eroded surface. Coquand and Augé[16] who have studied them believe them to be the products of hot springs in a Cretaceous lake or estuary while others believe they are the result of alteration of sedimentary beds and, therefore, secondary. Their direct relation to surface erosion is not clear though not impossible. Certain it is that they are conspicuously related to a definite stratigraphic horizon over wide areas.

Next to those of southern France the most important bauxite deposits in Europe are those in the Adriatic region.[17] The Ad-

[14] Adams, G. I., *op. cit.*

[15] Morse, P. F., "The Bauxite Deposits of Mississippi," Bull. 19, Mississippi Geological Survey, p. 32, 1923.

[16] Coquand, H., *Bull. Soc. Geol. France*, 2d Ser., vol. 28, 1870, p. 98. Augé *idem.*, 3d Series, vol. 16, p. 345, 1890.

[17] Communication from E. C. Harder.

riatic bauxite deposits are all closely related to limestones, some of Cretaceous age and others of Eocene age. Most commonly they lie on an irregularly eroded surface of Upper Cretaceous limestone but locally Lower Eocene limestone strata form underlying rocks. The bauxite deposits are overlain unconformably by Middle or Upper Eocene limestone. The contacts with the limestones are nearly always sharp. The association indicates that the formation of the bauxite occurred during a Lower Eocene or post-Lower Eocene erosion interval, during which at the same time a part or all of the Lower Eocene sediments were weathered and removed.

Bauxite is found at several localities in Germany as an alteration product of basalt.[18] The bauxite apparently directly overlies the basalt and has been developed in situ, a feature shown by the fact that it very often has the structure of the original rock.

The deposits in Scotland are apparently the result of alteration of basic lava flows under atmospheric conditions.[19] In Ireland likewise there are extensive deposits interlayered with basalt, which apparently represent interbasaltic erosion periods.[20]

The British Guiana deposits, according to Harrison,[21] show evidence of being the result of alteration of a porphyrite or tuff in places and of a muscovite-bearing pegmatite or aplite in others. Presumably the alteration has taken place by ordinary surface weathering under tropical conditions.

Fermor [22] states that certain of the Indian deposits are the direct result of the alteration in situ of a rock resembling an

[18] Streng, *Zeitschr. Deutsch. geol. Gesell.*, vol. 39, p. 621, 1887. Liebrich, *Inaug. Diss. Zurich*, 1891. Lang, J., *Ber. Deutsch. chem. Gesell.*, vol. 17, p. 2892, 1884. Delkenskamp, R., *Zeitschr. prakt. Geologie*, p. 306, 1904.

[19] Wilson, G. V., *Memoirs of the Geological Survey of Scotland*, "The Ayeshire Bauxitic Clay, 1922."

[20] Cole, G. A. J., and Others, "The Interbasaltic Rocks (Iron Ores and Bauxites) of Northeast Ireland," *Mem. Geological Survey of Ireland*, 1912, 129 pages. Kinahan, G. H., Trans. Manchester Geol. Soc., vol. 22, 1894, p. 458.

[21] Harrison, J. B., Reports and correspondence relative to bauxite in British Guiana, 1910–17; British Guiana Combined Court, Second Special Session, 1917, 31 pp., Georgetown, Demerara, 1919.

[22] Fermor, L. L., "Manganese in Laterite," *Memoirs of the Geol. Surv. of India*, 37–I.–II.

amygdaloidal, earthy trap. He states that there is a progressional change from the original basalt upward through a decomposed lavender-gray rock to the bauxite. He considers the alteration to be due to surface agencies.

McClaren,[23] however, on the contrary regards them as due to ascending water with concentration and deposition of Al_2O_3 and Fe_2O_3 by capillarity and evaporation. Alternate wet and dry seasons are necessary. Even so, this is a surface phenomenon and related to an erosion surface.

Finally, if we turn to laterites, of which bauxite is really a variety, the evidence is preponderatingly in favor of their origin by surface agencies.

Laterites[24] are quite widely distributed geographically, but occur in the largest amounts in the tropics especially in India,[25] British Guiana,[26] Madagascar,[27] West Africa,[28] New Caledonia,[29] Western Australia,[30] Rhodesia,[31] East Africa,[25] Malay Penin-

[23] McClaren, M., "On the Origin of Certain Laterites," Geol. Mag., vol. 3, pp. 537–547, 1906.

[24] Swanson, C. D., "The Origin, Distribution and Composition of Laterite," *Jour. Amer. Ceram. Soc.*, vol. 6, p. 1239, 1923.

[25] Fermor, L. L., "Manganese in Laterite," *Memoirs of the Geol. Surv. of India*, 37–I.–IV. Holland, T. H., "On the Constitution, Origin and Dehydration of Laterite," *Geol. Mag.*, vol. 10, pp. 59–69, 1903. Warth, H., and Warth, F. J., "The Composition of Indian Laterite," *Geol. Mag.*, vol. 10, pp. 154–159, 1903. McClaren, M., "On the Origin of Certain Laterites," *Geol. Mag.*, vol. 3, pp. 537–547, 1906. Lang, R., "Geologisch-Mineralogische Beobachtungen in Indien," *Centralblatt für Mineralogie*, pp. 641–653, 1914; 148–160, 1915. Fox, Cyril, "The Bauxite Resources of India," *Mining Mag.*, vol. 26, pp. 82–96, 1922. Also "Bauxite and Aluminous Laterite Occurrences of India," *Mem. Geological Survey of India*, vol. XLIX., Pt. 1, 1923, 207 pages. Dunstan, W. R., "Report on Laterite from the Central Provinces, India," *Record Geol. Surv. India*, vol. 32, pp. 213–220, 1904.

[26] Harrison, J. B., "Laterites in British Guiana," *Geol. Mag.*, vol. 7, pp. 439–452; 448–495; 555–562, 1910.

[27] La Croix, A., "Les Laterites de la Guinee et les Produits d'Alteration qui leux sont Associates," *Nouvelles Archives du Musee*, vol. 5, pp. 255–356, 1914.

[28] Campbell, J. M., "The Origin of Laterite," *Trans. Inst. Mining and Metallurgy*, vol. 19, pp. 432–435, 1909–10.

[29] Davis, W. M., "Metalliferous Laterites in New Caledonia," *Proc. Nat. Acad. Sci.*, vol. 4, pp. 275–280, 1918.

[30] Wollnough, W. G., "The Physiographic Significance of Laterites in Western Australia," *Geol. Mag.*, vol. 5, pp. 385–393, 1918.

sula,[25] Ceylon,[32] China,[32] and Caucasia.[32] They all show considerable similarity and may be discussed as a group. So far as the writer knows, all laterite deposits, exclusive of bauxite, have been shown to be the result of alteration under atmospheric conditions. The parent rock is not in all cases the same. It may apparently be any one of a number, especially basalt, volcanic ash, lavas, diabase, granite, serpentine or gneiss. The laterite may be formed in situ, or it may be later transported.

There is disagreement, however, concerning the character of the atmospheric conditions, solutions, and detailed reactions during the formation of the laterite. Some authors emphasize tropical conditions and absence of frost, others nitric acid in rainfall or volcanic acids, others even bacilli or other microörganisms, and still others the vegetation.

It should be pointed out here that in no proposed theory of origin is recourse made to the action of hot spring water or hydrothermal alteration. This seems to the author to be an important point in the consideration of the origin of bauxite since the latter is merely a phase of laterite, there being all gradations between the two.

In conclusion, the writer wishes to emphasize the general occurrence of bauxite and laterite with erosional surfaces; a mode of occurrence which suggests that weathering processes are the active agent in producing bauxite.

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[31] Mennel, F. P., "Notes on Rhodesian Laterite," *Geol. Mag.*, vol. 6, pp. 350–352, 1909.

[32] Bauer, Max, "Beitrag zur Kenntniss des Laterites, insbesondere dessen von Madagascar," *Neues Jarbuch für Mineralogie, Geologie, und Paloontolgie*, Festband, pp. 33–90, 1807–1907.

EDITORIAL

PROCESSES IN CONTACT METASOMATISM.

In classifications of mineral deposits according to their origin, those that are due to replacement of carbonate rocks at high temperatures, and more or less closely connected with intrusive igneous rocks, form a well-established and clearly defined group. Yet our understanding of the origin of this kind of deposits is still imperfect in many ways. Some of the problems are among those that confront us in all types of replacement, others are particular to the contact group. Let us consider briefly some of the latter.

One question concerns the form in which the "added" elements are carried in the presumably gaseous emanations. The two most common substances among those that are fixed in the new-formed minerals are silica and iron. It is believed for good reasons that iron may be carried as halogenides, and that reactions take place according to the formulæ:

$$2FeF_3 + 3CaCO_3 = Fe_2O_3 + 3CaF_2 + 3CO_2,$$
$$2FeCl_3 + 3CaCO_3 = Fe_2O_3 + 3CaCl_2 + 3CO_2.$$

The combination specularite-fluorite has been referred by Goldschmidt [1] to the first equation. If silica is present, the ferric iron may enter into andradite garnet instead. In magnesian rocks, as dolomite, minerals of the humite group may form and take up the fluorine. However, the addition of silica and fluorine to form humite or chondrodite appears to take place at a time distinctly—but not necessarily long—before the calcium carbonate set free by the breaking up of the dolomite is replaced by oxidic iron minerals. This is suggested by the observation frequently made that chondrodite and magnetite, when occurring in the same replacement body, are not regularly associated, and, when this

[1] "Die Kontaktmetamorphose im Kristianiagebiet."

happens, the fluo-silicate is always developed earlier than the magnetite.

Transportation as chloride, on the other hand, is indicated if there are minerals containing chlorine, such as soda scapolite, in the rocks associated with the contact ore deposit. A good example is given by the Philipsburg district, Montana.[2]

Yet if we study the numerous good descriptions of contact deposits that are available nowadays, we find that minerals containing halogens are absent from many of them, or that they are developed on a small scale only. The absence of minerals containing fluorine is decisive, as this substance can always be fixed. Chlorine presents a more difficult case, as it may travel long distances before encountering a rock of such composition that chlorine-bearing scapolite can be formed. However, even when taking this into account, halogens appear not to occur in such quantities as to explain all the addition of iron as oxides and silicates in the contact deposits. The quantity relations must also be kept in mind; if iron is transported as ferrous or ferric chloride, the forming of one ton of magnetite sets free chlorine compounds sufficient to form 14 or 21 tons, respectively, of soda scapolite. As there will generally be great quantities of lime present to form scapolite of an intermediate composition, these figures ought to be doubled to give the amounts of scapolite we have to expect under the given conditions. The difficulty is greatly increased if one assumes that the halogens were also responsible for the transport of silica.

It seems probable, then, that the transferring of iron as halogenides, which has been firmly proved in a number of cases, is not the only way in which the transport of this element is effected in the contact deposits. When we think of the silica, a transport in water solution (probably above the critical temperature) seems a reasonable explanation. But what about the iron? Certainly it is contrary to our established ideas of mineral deposition to imagine that iron can be carried, as oxygen compounds, in a gaseous water solution. Yet this possibility deserves serious consideration, even if the evidence for it so far is largely negative.

[2] Emmons and Calkins, P. P. 78, U. S. Geol. Survey.

Rather analogous to this argumentation, although taken from a different geological environment, is a train of thought that once caused the writer to point out briefly the possible application to the contact deposits of the idea just mentioned.[3] This was in a discussion of the large magmatic magnetite ores of northern Sweden (Kiruna type). In the porphyries associated with these ores there are often found vesicle fillings, apparently segregated from the immediately surrounding porphyry groundmass, that consist mainly of magnetite, amphibole, titanite, and apatite. These are explained as having crystallized from concentrated gaseous water solutions. Halogens have been present in certain cases, but are conspicuously lacking in others. If my interpretation of these magnetite nodules is correct, there is good reason to believe that oxidic iron compounds can be carried in gaseous water solutions also under other conditions, as in the contact deposits.

A new fact has been recorded that deserves to be mentioned in this connection: in a recently constructed refrigerator (system Munters-Platen), it was found that Fe_3O_4 formed at the welding of an iron tube was dissolved and redeposited as magnetite, the solvent being water with ammonia, at 140° C. and a pressure of 10 atmospheres.[4]

Other questions concern the concentration of the mineralizing solutions, and the differentiation in emanations that obviously have been derived from the same mother magma. One of the most remarkable examples of a concentration of rare metals in a deposit formed by high-temperature replacement of a carbonate rock is the cerium mine of Bastnäs, at Riddarhyttan in Central Sweden, which has been studied by the writer.[5] The gangue is actinolite. Sulphides of copper, molybdenum and bismuth are present, and also magnetite, but the predominant ore minerals in this particular deposit are cerium silicates, as cerite with about 60 per cent. oxides of the cerium metals, and orthite (allanite) with 27 per cent. Orthite has been found as a subordinated constitu-

[3] Geol. Fören. Förh., 34, 1912, p. 778.

[4] P. J. Holmquist, in Geol. Fören. Förh., 47, 1925, p. 143.

[5] "Sveriges Geologiska Undersökning," Ser. C, No. 304.

ent in replacement bodies of magnetite over a wide tract, and some tons of cerite have been mined at a neighboring mine, but the concentration at Bastnäs is nevertheless quite unique. There has been some uncertainty about the quantity of cerium minerals produced by this mine, as the older statistics are unsatisfactory. Recent sorting of old ore heaps now permits the statement that there has been mined ore containing at least 700 metric tons oxides of the cerium metals (cerium, lanthanum, neodymium, praseodymium). This is within an area of 20 by 15 meters, of which parts only are ore-bearing, and in a depth not exceeding 30 meters.

It seems inconceivable that cerium compounds in such proportions have entered also in the emanations active at the building up of the other, related ore bodies of the district. The concentration at Bastnäs, therefore, cannot be due solely to conditions particularly favorable for the fixing of the cerium, and the molybdenum. Instead, this remarkable deposit seems to be derived from a mineralizing emanation, in which just these elements were highly concentrated. The combination of elements instantly recalls that of certain pegmatites. In a way, the differentiation is still more striking than in them, for not only is the feldspar absent, but the metals of the cerium group are remarkably well separated from the other " rare earths," neither yttria nor thoria having been identified with certainty. A differentiation of this kind is probably due to fractional distillation from a body of volatile compounds, in its turn gathered from a large magma mass.

Mineral associations such as that of Bastnäs may perhaps be regarded as freaks of nature, but it is reasonable to expect from just such extraordinary products important information concerning the processes that built them up.

PER GEIJER.

GEOLOGY AS A GUIDE TO ORE.

GEOLOGY as a guide to ore is now being much assailed by the miner. Not that in parts like *structure* and *stratigraphy* it has not won his respect, but that in other parts like *genetic hypothesis* it has won only his distrust. Thus, we hear, Leadville gained striking benefits from the Emmons atlas, but found the monograph outside its literal passages merely confusing.

You come to me, the miner says, and cover my rugged ground with a smooth rule; I demand to know where my ore is and you term it shallow in type and certain to dwindle downward; but whether in the first or the third thousand feet you can only guess; without the facts your rule is only a pretext for prejudice; with the facts it would not be needed; the facts themselves remain as tangled as before and leave me no choice but routine exploration.

This opinion will be granted to contain much truth. It accords, indeed, with an opinion held by the geologists themselves, namely, that geology is overgrown on the speculative side. The miner refuses, as we must refuse, ideas untried by events and conclusions with meaning only in general. The failure of hypothesis to reveal the order of his ground is exactly what we should expect. That which badly serves science no less badly serves industry.

But this opinion in no sense condemns those ideas that spring out of a mine and form a true model of the pertinent arrangements there. The brute facts: trends up the bedding; continuations beyond a measured fault; concentrations in limestone under a porphyry roof: these are the guides that light the trails to ore in the untried darkness. Without exception, they must project from known ground and the shorter the projection the clearer the way. One immediate habit of occurrence out-values a hundred surmises fetched from a distance.

It is, then, not the science of geology but its speculative adornment that has failed. The science and its application equally suffer from such adornment and equally need more substance from pieces of ground in all their detail. To gain that sub-

stance is a toilsome problem of taking hold on a thousand awkward habits of occurrence. As this problem is conquered, geology will rise. But this problem will not be conquered by amateurs. Two score of first rank geologists are needed to dwell in the mining districts of North America and learn there, no less sharply than they now learn thin sections, the particulars of ground. Only thus, with such particulars schematized into a science, can geology take command as a guide to ore.

AUGUSTUS LOCKE.

DISCUSSION AND INFORMAL COMMUNICATIONS

METHODS OF PLOTTING WELL LOGS.

In geologic work, various means of plotting well logs and sections or representing them in graphic form have been employed. The simplest and perhaps the most useful for general purposes, is to plot the log graphically on a narrow strip of paper; on one side of which shale, sand, etc. can be represented by appropriate symbols and on the other side, descriptive material can be written.

A permanent and descriptive record in picture can be obtained by marking off glass tubes to scale and filling them with samples.

In recent correlation work in the Lake Basin Field, Stillwater County, Montana, Mr. E. T. Wright and the writer employed the following descriptive and illustrative method of plotting the logs. On a long narrow strip of paper, approximately one and one half inches wide, intervals were marked off on a scale of one inch equals fifty feet. As each well sample was studied and described, glue was spread on the paper strip in its proper place and a part of the crushed sample was placed on the glue. The surplus material was shaken off and the next sample was then arranged. Changes of color, character of sediments, etc., show up very well in this arrangement. Space was left on the side of the strip for any desired descriptive terms and items of interest.

A. W. Weeks.

Amarillo, Texas.

ENRICHMENT OF THE MESABI IRON ORES.

In a recent review of the general problem of enrichment of the iron ores of the Mesabi iron-mining district of Minnesota, Gruner [1] concluded that current knowledge of structure, texture

[1] Gruner, John W., "Contributions to the Geology of the Mesabi Range," Minn. Geol. Survey Bull. 19, 1924, pp. 65–67.

and chemical relations of the iron formation does not explain satisfactorily the origin of the hematite-limonite ore bodies. Some new analyses of formations near the ore now are available, so that a further consideration of the chemical and field relations is the particular contribution of this discussion.

The process of enrichment in this case generally is conceived to be fundamentally a matter of differential solution of the original taconite in such a manner that the percentage of residual silica was reduced and that of iron correlatively increased. The effectiveness of any solvent therefore depends upon the relative solution of silica and iron. The reagent must show a decided preference for the solution of silica in the presence of both silica and iron. Solvents of silica are acids, alkalies, and carbonated waters.[2] Acids however dissolve iron as well as silica and therefore may be eliminated. The ability of the alkalies to dissolve silica from protores of iron was demonstrated experimentally by Lovering but the amount of iron also dissolved, if any, was not stated. Carbonated waters, which dissolve silica, also take up some iron. However experiments conducted by Henkel show that bicarbonate solutions of calcium and magnesium retard the solution of iron from taconite without greatly affecting the solution of silica.[3] He found that such solutions soon became saturated with only small quantities of iron and yet they continued to dissolve silica in considerable quantities. This fact and the abundance of bicarbonates of calcium and magnesium in natural waters suggest that the answer to the problem is to be sought along these lines, especially since magnesium bicarbonate is a particularly effective reagent in dissolving silica[4] and in retarding the solution of iron.[5] A question remains, however, concern-

[2] Clarke, F. W., "Data of Geochemistry," U. S. Geol. Survey Bull. 695, p. 478. Gruner, John W., "The Origin of Sedimentary Iron Formations; the Biwabik Formation of the Mesabi Range," ECON. GEOL., XVII., Sept., 1922, p. 435. Lovering, T. S., "The Leaching of Iron Protores; Solution and Precipitation of Silica in Cold Water," ECON. GEOL., XVIII., Sept., 1923, p. 533.

[3] Henkel, Howard L., "The Solution of the Protores of Iron in Carbonated Waters, and their Effect on the Formation of Laterites and Replacement Deposits of Iron," Unpublished Senior Thesis, University of Minnesota, 1923.

[4] Lovering, T. S., *op. cit.*, p. 530.

[5] Henkel, Howard L., *op. cit.*

ing the relative effectiveness of solutions of the alkalies as compared with solutions of magnesium bicarbonate. The sources of these two types of solutions and their applicability therefore require further consideration.

The four extensive formations which might serve as sources are the Ely greenstone, the Lower-Middle Huronian sediments, the Giants Range granite and the Virginia slate. The last-named may be eliminated from consideration on account of its structural position and its relative impermeability.

The Lower-Middle Huronian sediments occur only in limited areas along the Mesabi Range, but doubtless were more extensive previously. Although variable in composition they contain an average of about 5 per cent. alkalies, 4 per cent. magnesia and 3 per cent. lime,[6] and therefore constitute a possible source of moderate amounts of solutions of the alkalies and alkaline earths. However they offer no particularly fruitful suggestions regarding the relative importance of the two types.

Recent analyses of the main body of the Giants Range granite show an average of 7.38 per cent. alkalies, 2.7 per cent. lime and 2.5 per cent. magnesia.[7] The small amount of alkaline earths clearly limit their efficacy. The figures for the alkalies on the other hand justify the suggestions of Van Hise, Leith and Mead,[8] and of Grout and Broderick[9] that alkaline solutions capable of leaching silica out of the taconite may have been derived from the Giants Range granite. The predominance of soda over potash in the ratio of about 5 to 2 would favor the development of alkaline solutions in abundance greater than normal to granitic terranes, since soda is leached more readily than potash. This soda-rich granite therefore may have been particularly effective.

[6] Unpublished analyses, furnished through the kindness of Dr. F. F. Grout.

[7] Allison, Ira S., "The Giants Range Batholith of Minnesota," *Jour. Geol.*, in press, 1925. Some highly hornblendic segregations at the border of the granite mass contain as much as 9 per cent. magnesia, but they are small and local, and therefore may be neglected here.

[8] Van Hise, C. R., Leith, C. K., and Mead, W. J., "Geology of the Lake Superior Region," U. S. Geol. Survey Mon. 52, 1911, pp. 538–539.

[9] Grout, F. F., and Broderick, T. M., "The Magnetite Deposits of the Eastern Mesabi Range," Minn. Geol. Survey Bull. 17, 1919, pp. 27–28 and 40.

On the other hand if magnesian solutions were the dominant factor they must have come from some other source, presumably the greenstone areas.[10] Thirty analyses of greenstone show an average of 6.73 per cent. lime and 6.41 per cent. magnesia, amounts sufficient to supply considerable quantities to groundwaters. In contrast with the Giants Range granite the Ely greenstone contains only about 3 per cent. alkalies.

To test the hypotheses one may compare the amount of enrichment of the taconite near granite, which is rich in alkalies, with that near the Ely greenstone, which is rich in magnesia. The Lower-Middle Huronian rocks do not throw much light on the matter since they are intermediate in character, being moderately rich both in alkalies and in magnesia. In making a test by the field associations of the ore bodies, however, certain difficulties must be admitted. The former extent of the granite and greenstone are almost unknown. Still the widespread presence of inclusions, roof pendants, *lit-par-lit* structure and other contact features show that the granite over considerable areas has not been eroded deeply. On the other hand the structural and topographic relations suggest that the greenstone areas along the Mesabi Range have suffered much more erosion than the granite, and any attempted corrections on that account would tend to magnify the relative influence of the greenstone. The readier facility of chemical weathering usually attributed to basic rocks also may be favorable to the greenstone. The effect of the overlap of Upper Huronian sediments is another complication difficult to evaluate. Under the limitations the only recourse is to make the test by the present field relations.

On a detailed geologic map of the district it may be seen that the ore bodies in the vicinity of Biwabik, Virginia, Mountain Iron, Hibbing and Nashwauk are more closely associated with outcrops of greenstone than of granite, while those near Mesaba, Kinney, Buhl, Chisholm, Keewatin, Calumet, Marble and others

[10] It is possible that Paleozoic dolomites once may have covered the region and that their weathering may have yielded effective solvents in so far as groundwaters descending from them were not halted or excluded by the Virginia slate. No traces of such dolomites are known however.

westward to Coleraine are more closely associated with outcrops of granite. The former group near the greenstone includes by far the larger quantity of ore. Thus the field relations seem to indicate that the alkaline solutions derived from the granite contributed less toward the enrichment of the iron ores than did magnesian solutions that may have come from the greenstone. Incidentally these field relations seem to validate the experimental work of Lovering and Henkel on the solubility of silica in magnesian solutions.

IRA S. ALLISON.

UNIVERSITY OF MINNESOTA,
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CALIFORNIA OIL FIELD WATERS.[1]

Sir: In a recent paper by Dr. Chase Palmer, on "California oil field waters," (ECON. GEOL., vol. XIX., No. 7, pp. 623–635, 1924), he challenges the generally accepted belief that sulphate waters coming in contact with petroleum deposits are reduced by the hydrocarbons from petroleum. Doctor Palmer[2] states that the alkaline sulphide waters associated with the oil in southern California have not been formed by reduction of sulphate waters by hydrocarbon gases. He says that[3]

> The alkaline sulphide waters are derived from alkaline carbonate waters; they are alkaline carbonate waters more or less altered by absorption of volatile sulphur compounds emanating from the oil.

Of these volatile sulphur compounds the only one that he discusses specifically is carbonoxysulfide concerning which he remarks:

> A sulphur-bearing gas, carbonoxysulfide, evolved from the sulphur compounds of the oil, migrates to alkaline carbonate waters which decompose the gas and entrap its sulphur.

Doctor Palmer presents some plausible arguments in favor of

[1] Published by permission of the Director, United States Geological Survey, Washington, D. C.

[2] Palmer, Chase, *op. cit.*, p. 634.

[3] Palmer, Chase, *op. cit.*, p. 634.

carbonoxysulfide being responsible for the sulfide-bearing waters in oil fields and calls attention to the fact that carbonoxysulfide has been reported from a thermal spring at Harkany, Hungary, and from a cold spring at Parad, Hungary, and he suggests that carbonoxysulfide is probably widely distributed in nature. He fails, however, to state whether or not in his investigations he has found carbonoxysulfide in California petroleum and associated ground waters. If carbonoxysulfide derived from petroleum is present in the ground waters of California oil fields, it would be very desirable to have data as to the quantity of the gas, places of occurrence, and other environmental factors pertaining to it.

B. COLEMAN RENICK.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.

PHOSPHATE DEPOSITS OF THE PACIFIC.

Sir: Having read with interest the paper on " Phosphate Deposits of the Pacific " by F. Danvers Power, I should like to offer two suggestions to the author of the paper and his readers.

The excess of CaO, amounting to 4–5 per cent., which the author noted in analyses of the phosphate rock, is probably due to the fact that the rock consists largely of the amorphous mineral collophane, which is not merely tribasic calcium phosphate, but a compound containing $CaCO_3$ and often an excess of CaO chemically combined with tri-calcium phosphate. Collophane is the characteristic mineral in sedimentary phosphate deposits.

The author describes the occurrence of the phosphate rock in a network of narrow chasms separated by pinnacles of limestone or dolomite. He concludes that, before the epoch of phosphate deposition, the chasms were eroded by wave and current action, leaving the pinnacles thus isolated. It is difficult to reconcile this with the ordinary behavior of wave erosion, although some of the more isolated pinnacles do bear some resemblance to rock stacks upon a wave-cut platform. On the other hand, such pinnacles and chasms are typical phenomena, revealed in many situations, where a residual soil has been artificially cleaned off

from a limestone surface. They are to be found in many places far from the sea. In such cases the circulation of ground-water downward, along cracks or other avenues of movement, has resulted in the widening of such openings by solution. These clefts are progressively filled with the residuum—usually red clay—which collects upon the surface of rock thus decomposing. In the phosphate district of central Florida, the worked-out quarries are a network of channels with intervening cones and pyramids of limestone, almost identical with those shown in the illustrations of Mr. Power. After a prolonged study of these deposits, Sellards concluded that the reticulate cover of phosphate rock represents the irregularly phosphatized part of an Eocene limestone, together with the residuum of an overlying more or less phosphatic limestone, which furnished the descending solutions. The latter followed the cracks in the limestone and caused the alteration of the rock along the walls of the cracks. The effects decreased downward as the solution became depleted by reactions near the surface. The reviewer suggests that the pinnacles and chasms on the Pacific Islands, as described by Mr. Power, may well have had a similar origin, except that bird guano was the source of the solutions.

ELIOT BLACKWELDER.

STANFORD UNIVERSITY, CALIFORNIA.

NOV 10 1920

REVIEWS

Central Black Hills Folio, South Dakota. U. S. Geol. Survey, Folio No. 219: by N. H. Darton and Sidney Page. Washington, D. C., 1925.

The latest Geological Folio published by the United States Geological Survey includes the Deadwood, Rapid, Harney Peak, and Hermosa quadrangles in the southwestern part of South Dakota.

The maps, diagrams, and photographic illustrations are plentiful and in keeping with the usual standard of excellence maintained by the Survey. Contrary to custom some of the maps are larger than the folio pages and consequently must be folded. This is necessitated by the use of a scale of 1/125000 for the topographic, areal geology and structure section sheets. These are made to include one degree of latitude and longitude, the whole of the area discussed. Besides this there is a larger scale (1/62500) areal geology sheet of the Lead quadrangle and artesian water supply sheets of the Deadwood, Rapid and Hermosa Quadrangles. These are maps of the usual size with the 1/125000 scale.

The folio is a large one. It includes paragraphs on settlement, timber, and climate under the heading "geography." A chapter on the geology of the general region is followed by one on descriptive geology which contains the usual descriptions of formations and an interesting discussion of the mechanics of intrusion of the Algonkian granite.

The conclusion reached after a careful study of the relations of the Algonkian granite to the rocks which it has intruded is that it came into place mainly by displacing the country rock and only in small part by assimilating it.

The chapter on structural geology describes the structure under the following headings: "Structure in Algonkian Rocks; Structure in Cambrian to Cretaceous Beds; Structural Features formed by Tertiary Igneous Intrusions. The last one is particularly well illustrated by diagrams. It is followed by a discussion of the mechanics of intrusion of the Tertiary igneous rocks which shows that the shapes of the igneous masses have been greatly influenced by the structure of the invaded rocks.

The consideration of the cause of the violent rupture and uplift of 1,460 feet of beds at the summit of the uplift caused by the Crow Peak igneous mass and other similar intrusives leads to the conclusion that the form of the upper surface of a laccolith might be materially affected by the progressive increase of the viscosity of the magma during injection.

The Shonkin Sag Laccolith is presented as one extreme illustrating violent intrusive force spread evenly over the surface of intrusion by hydrostatic pressure in a fluid magma and so capable of lifting a cylindrical mass of rock above it. The other extreme is shown by the type which the Judith Mt. mass approaches and which Crow Peak is believed to illustrate even better. This is caused by slow intrusion allowing hydrostatic pressure to be interfered with by increasing viscosity and a consequent unequal distribution of pressure with its final concentration immediately over the source of supply with resulting rupture.

The chapter on Economic Geology commences with a classification of the metalliferous deposits of the Black Hills. This is followed by a description of the famous Homestake gold mine. The origin of the ore is attributed to the effect of the invasion of the schists by the granite of Algonkian age at a late stage in the metamorphism of the schists. In view of the recent controversy as to whether the mineralization is of pre-Cambrian or Tertiary age, Mr. Page's reasons for assigning a pre-Cambrian age to the gold ores may be quoted:

1. "The principal sulphides of the Homestake ore, named in the order of their introduction, are arsenopyrite, pyrrhotite, and pyrite. Gold is associated with all these sulfides. Pyrrhotite, which is abudant in the Homestake ore, is absent in the Tertiary ores, and there is evidence that much gold was introduced with pyrrhotite."

2. "The gold of the Homestake ore is relatively coarse as compared with the gold of the Tertiary ores, and 70 per cent. of it is caught by amalgamation. The gold of the Tertiary ores occurs principally as telluride, and these ores must be treated by cyaniding. There are practically no tellurides in the Homestake ores."

3. "The Homestake ores within the principal shear zone that limits the main ore bodies on the west are folded and sheared. The shearing was undoubtedly the result of compression during pre-Cambrian time. The sulfides and gold that suffered this disturbance must be pre-Cambrian."

4. "It seems evident that the placer deposits in the conglomerate of the Deadwood formation were formed from the outcrops of the Homestake lode as the Cambrian seas advanced."

Tertiary porphyry later invaded the Homestake ores and destroyed the continuity of the deposits. Solutions of still later date, though still in the Tertiary, are admitted to have contributed some gold but the amount so introduced is believed to be small compared to that introduced in pre-Cambrian time.

Following this there are short descriptions of the mineralization of the quartz veins, shear zones and replacement lodes in the Algonkian rocks; and of the deposits in the Paleozoic formations and the Tertiary porphyry.

The tungsten of the Cambrian formations and pegmatite dikes and veins; the tin and mica of the pegmatite dikes and veins; and the lithia minerals of the pegmatite dikes are treated separately. Structural and other materials and mineral fuels are the subject of another chapter. This very thorough and careful description of the region is brought to a close by a chapter on water supply supplemented by the three artesian water supply maps mentioned before.

The folio is in many ways the best published by the United States Geological Survey to date. It is a distinct credit to the authors, and well worth the study of anyone interested in any of the many phases of geology there discussed.

WILLIAM M. AGAR.

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"Paraffin Dirt": Its Nature, Origin, Mode of Occurrence, and Significance as an Indication of Petroleum. By H. B. MILNER. Mining Mag. (London), vol. 32, 1925, pp. 78–85.

This, the latest discussion of the origin of paraffin dirt, was written by Professor Milner of the Royal School of Mines after a visit to ten Gulf Coast salt domes under the guidance of Wallace E. Pratt. Such exceptional opportunities to study the material in the field, together with chemical studies by Professor A. Wolf of samples taken to England, renders the report authoritative. It is pleasing to note the American references.

Paraffin dirt is "essentially a form of argillaceous soil though possessing certain physical properties distinguishing it as an uncommon facies. . . . The peculiar physical property . . . is undoubtedly its texture, what has been termed its 'rubbery' or 'curdy' character, causing it when wet or even only damp to exhibit a remarkable degree of resilience, more strikingly developed in some cases than in others."

"The usual occurrence . . . in low, moist areas is significant, though not invariable. . . . It has been discovered on high ground, free from inundation." Other factors of environment are abundant vegetable matter, marsh gas evolved from swampy soils, and a sub-tropical climate. The thickness of deposits ranges from 2 to 7 feet according to Hager.

Petrological study shows structureless, somewhat plastic clay with more or less fine sand, sometimes constituting 25 per cent. of the sample. The clay is presumably colloidal with colloidal organic matter (humus), permeated by vegetable remains which have an organic structure resembling that of peat. Nothing unusual was noted about the quartz or heavy minerals. The microscope "shows that 'paraffin dirt' is a true soil in all respects and contains no fundamental structure or mineral composition

differentiating it from other soils. . . . It may be safely assumed, therefore, that the peculiar properties . . . have been developed subsequent to its formation as a soil . . . and are in no way inherent to the substance as first accumulated." Also, the colloidal character is the same as any other form of soil, yet the higher percentage of colloids imparts a high adsorptive capacity. It has been formed under anaërobic conditions and is very closely allied to true peat soil. Chemical analyses confirm those previously published by Brokaw; no paraffin or asphaltic hydrocarbons were found and the content of organic matter is abnormally high.

Milner's conclusions are vague because he finds no inherent difference between paraffin dirt and ordinary soil except increase in colloidal and organic content due to "conditions peculiar to the soil environment of 'paraffin dirt' to which its adsorptive powers are strongly reactive." Adsorptive saturation is incomplete, producing an "unstable physical state"; and the controlling factors which permit this condition are "bound up with the nature and concentration of the impregnating fluids, the presence of meteoric water, and indirectly to microbiological influence."

Geologists have failed to learn the difference between paraffin dirt and ordinary soil, although Milner's study is the most comprehensive which has appeared and it points to the field of study wherein solution may be found. Soils are known best to the agriculturists who turn to biologists for assistance, as geologists turn to petrographers and chemists. Gas and clay soil are prerequisites to the formation of paraffin dirt, as stated by Pratt in a communication to Milner. Does not the gas impregnate the common soil of the Gulf Coast or of eastern Texas or northern Louisiana where the deposits occur and does not this impregnation permit the growth of microscopic organisms (algae, anaërobic bacteria, etc.) whose presence causes the clay at these gas seepages to assume the rubbery texture? Biological phases of geology have been neglected. Perhaps some alga is associated with paraffin dirt just as certain red algæ, instead of mineral matter, impart the red color to certain red salts. The problem invites biological study.

SIDNEY POWERS.

TULSA, OKLA.

Geology of the Republic of Haiti. By WENDELL P. WOODRING, JOHN S. BROWN, AND WILBUR S. BURBANK. Geological Survey of the Republic of Haiti. 630 pp. 37 text figures, 40 plates. Port-au-Prince, 1924.

This report is the outcome of a reconnaissance geological survey of the Republic of Haiti, the scientific personnel of which was furnished by the United States Geological Survey.

The scope of the report is much wider than its title would indicate. The material is presented in five parts, the titles of which are; Geography, Geology, Geomorphology, Mineral Resources, and Water Resources. Each part is comprehensive and, depending on whether the subject matter constitutes a speciality of one of the authors, is written by one or more of them. This book not only gives a thorough treatment of the geology of the Republic but also is successful in presenting a clear idea of the general character of the country and its resources. It can accordingly be read with profit by any one wishing to acquire a general knowledge of the Republic including its available and potential resources.

CARL TOLMAN.

Coal and Civilization. By E. C. JEFFREY. 178 pp. with 45 illustrations. The Macmillan Company, New York, 1925.

The purpose of this book is twofold: first, to point out the fundamental importance of coal to our modern civilization; and second, to demonstrate its structure and origin. By the use of methods of microscopic study devised by the author it is shown that all coals consist of modified wood, charred wood (supposed to be derived from forest fires), spores, and dark matrix in varying proportions. Cannel coals, for example, consist predominantly of spores while the high grade coking coals are composed almost exclusively of modified wood, but the color and luster of a coal are no indices of its composition. Practically no coals are derived from true peat but they have accumulated as transported lake-bottom mucks in warm climates under permanent water cover. Biochemical activity is unimportant in the formation of coal from vegetable materials; the important factors are secular hydrolysis and increased temperature and pressure.

"Coal and Civilization" is an interesting and readable book. The illustrations, which are nearly all photomicrographs of coal, are excellent.

JOHN B. STONE.

SCIENTIFIC NOTES AND NEWS

J. B. Tyrrell of Toronto, manager of the Kirkland Lake gold mine, is visiting London, England.

L. T. Burwash, formerly of the Canadian Department of the Interior, Yukon Territory, is now engaged in exploration of the natural resources of the northern coasts of Canada.

Hugh D. Miser has succeeded Wilbur A. Nelson as state geologist of Tennessee. His term of office commenced September 1st.

Edward Sampson, associate geologist of the U. S. Geological Survey, has been appointed assistant professor of geology at Princeton University.

H. G. Ferguson has been at Mina, Nevada, completing work on the U. S. Geological Survey map of the Hawthorne quadrangle.

Gerald Fitzgerald reports the discovery of oil in regions visited on the Arctic slope of Alaska by a U. S. Geological Survey party, of which he was head.

Wilbur A. Nelson, formerly state geologist of Tennessee, is now head of the Geological Department of the University of Virginia and director of the Virginia geological survey.

Gilbert H. Cady, head of the Department of Geology of the University of Arkansas, Fayetteville, has been appointed senior geologist in charge of coal studies, to succeed Dr. H. E. Culver, who has accepted the headship of the Department of Geology at Washington State College.

Frederick G. Clapp has returned to New York City after nearly two years in Australasia, and will continue his professional practice at the old address, 30 Church Street.

E. DeGolyer, of New York City, has been on a trip to London recently.

O. E. Meinzer, of the U. S. Geological Survey, has been making an investigation of the public water supply at Sheldon, So. Dak., and will also study the geologic conditions affecting the water supplies for Canton, So. Dak., and for the insane asylum for Indians at Canton.

Courtenay DeKalb, of Tucson, Arizona, is to be head of the Department of Mines in the University of Alabama.

William Porri, formerly manager of the New Dominion Copper Company at Globe, Arizona, has gone to Alamos, Sonora, Mexico, where he will be manager for the Alamos Silver Mining Company.

G. C. Klugg, of London, returned to England recently after a trip to Australia to visit various mining centers of the Australian Commonwealth.

R. E. Hanley has succeeded O. J. Egleston as general manager of the Mammoth Copper Company. Mr. Egleston has gone to Alaska to take charge of work for the U. S. Smelting Company at Nome.

Alexander Deussen, of Houston, Texas, is vice-president of the Marland Oil Company of Texas, and in charge of the work in the Gulf Coastal Plain of Texas and Louisiana.

John Stansfield has been appointed head of the Department of Geology at the State School of Mines, Butte, Montana.

G. H. Chadwick is taking the place of Professor H. F. Cleland at Williams College for a year while the latter is on sabbatical leave.

The Department of Geology of the University of North Carolina, under the direction of Professor W. F. Prouty, conducted a field course during July and August through the central and western portion of Georgia, Eastern Tennessee, and Southwestern Virginia, visiting the more important mining and quarrying centers.

John C. Greenway has returned to Ajo, Arizona, and opened an office in the Valley Bank Building.

E. E. McCarthy, resident manager of the Yukon Gold Company in the Malay States, has recently been visiting New York.

W. C. Mansfield of the U. S. Geological Survey is now in Florida doing field work on the Upper Miocene of that State.

C. M. Yeakel died on July 4th, while in Venezuela working for the Atlantic Refining Company.

Glenn Beckley Morgan died at Rolla, Missouri, on September 7th, aged 48 years, after three years of ill health. He was born in Indianapolis, Ind.; graduated from the School of Mines at Rolla in 1904; was engaged in work for the U. S. Geological Survey, and later in professional work. He was State Geologist of Wyoming from 1918 to 1922, and since then has been consulting geologist.